ASSESSMENTS OF VOICE USE, VOICE QUALITY, AND PERCEIVED SINGING VOICE FUNCTION AMONG COLLEGE/UNIVERSITY SINGING STUDENTS AGES 18-24 THROUGH SIMULTANEOUS AMBULATORY MONITORING WITH ACCELEROMETER AND ACOUSTIC TRANSDUCERS

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Abstract

Previous vocal dose studies have analyzed the duration, intensity and frequency (in Hz) of voice use among college/university singing students through ambulatory monitoring. However, no ambulatory studies of this population have acquired these vocal dose data simultaneously with acoustic measures of voice quality in order to facilitate direct comparisons of voice use with voice quality during the same voicing period.

The purpose of this study was to assess the voice use, voice quality, and perceived singing voice function of college/university singing students (*N* = 19), ages 18-24 years, enrolled in both voice lessons and choir, through (a) measurements of vocal dose and voice quality collected over 3 full days of ambulatory monitoring with an unfiltered neck accelerometer signal acquired with the Sonovox AB VoxLog™ portable voice analyzer collar; (b) measurements of voice quality during singing and speaking vocal tasks acquired at 3 different times of day by the VoxLog™ collar's acoustic and accelerometer transducers; and (c) multiple applications of the Evaluation of the Ability to Sing Easily (EASE) questionnaire about perceived singing voice function. Vocal dose metrics included phonation percentage, dose time, cycle dose, and distance dose. Voice quality measures included fundamental frequency (F_0), perceived pitch (P_0), dB SPL, LTAS slope, alpha ratio, dB SPL 1-3 kHz, pitch strength, shimmer, jitter, and harmonic-to-noise ratio.

Major findings indicated that among these students (a) higher vocal doses correlated significantly with greater voice amplitude, more vocal clarity, and less perturbation; (b) there were significant differences in vocal dose and voice quality among non-singing, solo singing, and choral singing time periods; (c) analysis of repeated vocal tasks with the acoustic transducer showed that F_0, P_0, SPL, and resonance measures displayed increases from morning to afternoon to evening; (d) less perceived ability to sing easily correlated positively with higher frequency and lower amplitude when analyzing repeated vocal tasks with the acoustic transducer; and (e) the two transducers exhibited significant and irregular differences in data simultaneously obtained for 8 of the 10 measures of voice quality.

Keywords: voice use, vocal dose, ambulatory voice monitoring, voice dosimeter, voice science, vocal pedagogy, voice quality

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CHAPTER 1

Introduction

Perusal of the research literature reveals a limited amount of empirical data regarding the typical vocal dose acquired by college and university students who engage in multiple singing activities during the course of their waking hours. To date, moreover, no ambulatory field study of this population simultaneously acquires a combination of participants' vocal dose and voice quality data to examine how the quality of singing and speaking vocal production might relate to the vocal dose and the vocal efficiency of each individual.

Such data could interest vocal music instructors, speech language pathologists, and laryngologists, because older adolescence is a period marked by constant physical change in laryngeal structures. Laryngeal structures of both males and females undergo documented changes attributable to puberty (Cooksey, 2000; Gackle, 2000; Titze, 2000). In males, the size of the larynx and the length of the vocal folds increase, significantly decreasing F_0, and the thyroarytenoid muscle thickens (Titze, 2000). Cooksey (2000) reports that while the largest of these changes for males typically occur prior to the time students enter a college or university vocal program at about 18 years of age, laryngeal structures are still developing.

In female voices, the onset of menstruation seems to coincide with a lowering of average speaking fundamental frequency (F_0), but at about 16 years of age, the average speaking fundamental frequency still remains above the adult norm (Gackle, 2000). The female vocal tract may not reach its full adult size until around the age of 20 or 21 years (Gackle, 2000).

In both males and females, the layered structure in the lamina propria of the vocal folds (which influences the complexity of sound produced by the vocal source) does not finish developing until around 17 years of age (Colton, 2006; Kosuke, Masumi, Kotaro & Hajime, 2000). The larynx lowers in relation to the cervical vertebrae from the lower border of C6 following puberty to the upper area of C7 by about 20 years of age and continues to settle slightly from that position throughout life (Thurman & Klitzke, 2000). Further stabilization continues until the late 20s or early 30s (Cooksey, 2000). The cartilages of the larynx ossify throughout life, increasing laryngeal stability towards mid-life (Titze, 2000). Because of these ongoing changes, Titze and others suggest that voice teachers delay specific voice classification until after adolescent voice development is largely complete sometime in the early 20s.

Around the age of 18 years, many young people, with their still changing and stabilizing voices, traditionally enter an undergraduate college experience. The first years of college study are among the most formative years of many individuals' lives. Students leave home and begin, for the first time of their own accord, to establish patterns and habits that they may well retain for the remainder of their lives. In this environment, singers frequently experience heavy vocal demands: voice lessons, choral and theatre activities, student-organized music groups, church activities, busy social lives, sports, and sometimes jobs that involve heavy vocal demands (e.g. waiting tables or college phonathons) (Austin & Hunter, 2009; Gaskill, Cowgill, & O'Brien, 2013; Manternach, 2011b; Schloneger, 2010). These young people are unsupervised for the first time in their lives, and even future professional voice users in training may develop less than desirable sleep and vocal hygiene habits (Manternach, 2011b; Timmermans et al., 2002). Future professional voice users may also lack or ignore training in vocal hygiene (Timmermans, De Bodt, Wuyts, & Van de Heyning, 2005). Because these students may be unaware of the negative, over time effects of heavy vocal loads on their abilities to phonate efficiently, concern for these students' well-being becomes apparent.

During the traditional college or university years, it is important that voice pedagogues have the greatest possible understanding of the ways voice use could affect the quality of these students' voices and vocal health, so that they can help guide these young people to establish best practices and positive, lifelong habits. College and university professors, despite their best intentions, may unintentionally contribute to these vocal concerns through college sponsored activities, especially during intensive rehearsal periods (Austin & Hunter, 2009; Gaskill, Cowgill, & O'Brien, 2013; Schloneger, 2010). These activities, along with all the other intensive activities undertaken by these students, may push voices to the point in vocal loading where vocal efficiency begins to decline The development of scientifically based guidelines for permissible levels of vocal dose would help college faculty advise undergraduate singers about appropriate levels of rehearsal and performance time as well as parameters of speaking voice use and voice care.

The Need for Acoustic Correlates of Vocal Fatigue

Although teachers and students would benefit from published, scientific standards of voice use for young singers with developing and stabilizing vocal instruments, formulation of such standards remains an elusive task. To date, despite a considerable body of literature reporting on the vibratory, acoustic, and perceived effects of vocal loading among various populations, there remains a paucity of data pinpointing when particular vocal inefficiencies may first develop.

A large part of the problem remains that scientists have yet to succeed in finding acoustic measures that clearly identify changes in the voice following a period of vocal loading, short of a vocal pathology. In a 30-year summary of research on vocal fatigue, Welham and MacIagan (2003) report "a particularly critical shortage of data concerning the nature of vocal function changes following singing or acting performance" (p.28). Hunter and Titze (2009) reiterate this assertion. Laboratory studies of vocal loading have found limited positive correlations between acoustic measures of vocal sound and physical measures of vocal fatigue (Boucher, 2008; Boucher & Ayad, 2010) or singer perceptions of vocal fatigue (Kitch, Oates, & Greenwood, 1996).

Although "vocal fatigue" remains a largely subjective term (Vilkman, 2004), it may be an appropriate term when thinking about non-dysphonic voices. In order to fully understand the effects of vocal loading, there is a need to differentiate potential correlations between vocal dose and voice quality changes in reportedly healthy voices from such potential correlations that result from the deleterious effects of a vocal pathology. Therefore, the following definition, adapted by Welham and MacIagan (2003) from an earlier definition by Scherer (1987), will be employed when alluding to vocal fatigue in this study:

> Vocal fatigue is used to denote negative vocal adaptation that occurs as a consequence of prolonged voice use. Negative vocal adaptation is viewed as a perceptual, acoustic, or physiologic concept, indicating undesirable or unexpected changes in the functional status of the laryngeal mechanism. (p. 22)

Acoustic and perceptual changes associated with vocal fatigue may have a variety of physiological causes. These causes may include neuromuscular fatigue involving the extrinsic or intrinsic vocal musculature, increased vocal fold viscosity, non-muscular tissue strain (i.e., phonotrauma), respiratory muscle fatigue, individual anatomical and physiological differences, and the demands of individual vocal tasks (Chang, 2000; Welham & Maclagan, 2003). Perhaps in part due to the complexity of these factors, the research literature has yet to establish a relationship among vocal fatigue, vocal efficiency, and vocal dose.

Likewise, a relationship between vocal load and the voice's ability to recover from stress (i.e., recovery time) is not yet entirely clear (Titze, 2009). Hunter and Titze (2009) quantify the recovery of teachers' (*N* = 86) voices following a 2-hour oral reading vocal loading exercise. Using multiple perceptual methods, their study notes strong short term recovery, with 90% recovery within 4 to 6 hours and full recovery at 12 to 18 hours. The study concludes that vocal recovery is similar to the healing of chronic rather than acute wounds and that "with daily use of the voice, there is continual damage and the healing mechanism is in a state of constant repair" (p. 458).

Self-Perception of Vocal Fatigue

Given the complex factors involved in measuring vocal fatigue, measures of self-perceived changes in vocal efficiency could be a place to begin in determining the point at which vocal loading leads to declines in vocal function. Several validated measures assess the perceived severity of vocal pathologies, most notably the Voice Handicap Index (Jacobson, 1997) and the Singing Voice Handicap Index (Cohen et al., 2007). These tools, however, are designed to test the severity of vocal problems. As such, they are not adequately sensitive to measure the self-perception of vocal fatigue among individuals lacking any vocal pathology. A recently validated self-rating tool, the Evaluation of the Ability to Sing Easily (EASE) questionnaire, focuses on the more subtle changes in self-perceived vocal function that can occur in otherwise healthy singers (Phyland, Pallant et al., 2013, p. 454). This type of self-report appears to be a reasonable dependent measure for a study of changes that occur in undergraduate student singers. The EASE questionnaire could be an especially appropriate tool when combined with real-time ambulatory measures of vocal dose and voice quality.

Vocal Dose

In correspondence with questions regarding vocal fatigue, explorations of possible connections between vocal dose and changes in voice quality through refinements in voice dosimetry remains an ongoing task. Following the creation and commercial release of portable voice dosimeters over the last decade, several published studies began to quantify a typical vocal dose among different populations, mostly among teachers (Bottalico & Astolfi, 2012; Franca, 2013; Gaskill, O'Brien, & Tinter, 2012; Hunter & Titze, 2010; Morrow & Connor, 2011a) and various populations of singers, including high school students (Daugherty, Manternach, & Price, 2011), graduate student vocalists (Gaskill, Cowgill, & Tinter, 2013; Schloneger, 2011), and undergraduate student vocalists (Gaskill, Cowgill, & O'Brien, 2013). Although these studies provide data that begin to address questions about the typical vocal doses among different populations, voice data collected through these commercial dosimeters include only processed information about the duration, frequency, and amplitude of vibrations. They tell us little about the efficiency with which those vibrations are produced.

Voice Quality

Factors beyond simple vocal dose may contribute to a change in vocal function during intensive periods of voice use. Factors potentially impacting voice quality, such as the quality of speaking and singing technique, hydration levels, and sleep, might also contribute. To date, dosimeter studies largely do not address voice quality alongside vocal dose because the dosimeters used in these studies do not allow for simultaneous real-time analysis of spectral and voice perturbation data.

Such measurements in the study of young singers could be important in understanding reasons why some young singers fatigue more quickly than others. Anecdotal experience (Colton, 2006, p. 232) suggests that some young singers may cultivate strong, efficient singing techniques through voice lessons or choral experience yet develop vocal problems due to poor vocal hygiene, unhealthy quality of speech, and heavy speech doses. The opposite could also be true if young vocalists with efficient speech habits develop inefficient singing habits. While studies exist that alternately analyze the vocal dose (Gaskill, Cowgill, & O'Brien, 2013; Gaskill, Cowgill, & Tinter, 2013; Manternach, 2011b; Schloneger, 2010, 2011) and voice quality (Leino, 2009; Sisakun, 2000) of young university students, none of these studies include vocal dose and voice quality data acquired simultaneously through ambulatory monitoring.

A New Method for Voice Dosimetry

The processed acquisition of three preselected data points (presence of voicing, frequency in Hz, and SPL) every 20-30ms from an accelerometer transducer constitutes the basis of voice dosimetry employed over the last decade. The accelerometer measures skin vibrations in the neck to isolate the participant's phonation activity. The processed signal allows for the acquisition of important vocal dose information without the privacy concerns of audio recording, and it does so in a way that limits data file size to dimensions appropriate for an earlier generation of computers. Such devices, however, have little capacity to assist researchers with simultaneously assessing the quality of vocal production. Ability to incorporate spectral and voice perturbation quality measures in voice dosimetry could help provide a fuller picture of how the quality of voice production may interact with the effects of vocal dose.

The rapid development of computer processing and memory now enables researchers to address this issue at an inexpensive cost. Current portable computer memory allows for the recording of the full, unprocessed accelerometer signal by any quality, commercially produced digital recorder for long periods of time. This full, unfiltered accelerometer signal permits voice quality analysis of the same recorded data already used to calculate dose with limited contamination of ambient sound (Hillman et al., 2013; Mehta, Zanartu, Feng, Cheyne, & Hillman, 2012; Mehta et al., 2013; Zanartu, 2010).

Figure 1. VoxLog™ collar.

Hunter (2013) proposes and discusses the benefits and limitations of a new budget dosimetry system that could be employed to record this unfiltered signal. Sonovox AB in Sweden is producing a new dosimeter device, the VoxLog™ portable voice analyzer (hereafter, VoxLog) that includes an adjustable neck collar which allows for easy on and off without surgical adhesive (Figure 1). The VoxLog collar houses two transducers: a quality contact accelerometer and an audio microphone that samples airborne acoustics. Hunter suggests that the neck collar from the VoxLog could be employed with a standard digital recorder with a 16GB SD card to record the full signal from both microphones for more than 20 consecutive hours. This capability allows for the analysis of vocal dose and voice quality measures acquired from the accelerometer data for ambulatory monitoring periods. It also permits the analysis and comparison of data from both the contact accelerometer (which measures vocal source vibrations) and acoustic microphones (which measures the participant’s vocal sound filtered by the vocal tract and ambient sounds) for periods when minimal ambient sound is present.

Current dosimeters, including the full VoxLog device, retail for about $5,000 per unit, a cost that may limit their accessibility, especially for voice pedagogues and researchers unfunded by grants. The use of only the VoxLog microphone collar with a standard digital recorder, however, combined with data analysis protocols developed for this study, may permit studies of voice for a fraction of the cost of current studies completed with commercially produced dosimeters. The equipment used for this study could potentially cost less than $1,000, an amount accessible to most university vocal or SLP departments, private voice studios, and medical voice clinics. The affordable prices of the neck collar transducers and commercially available recording devices, when used with free Open Source Software for digital processing and MATLAB (or an equivalent data processing program) on a standard laptop or desktop computer, potentially make the analysis of vocal dose and quality readily available to voice researchers and pedagogues. This study establishes protocols for VoxLog data analysis in this manner. By comparing perceived singing voice function, vocal dose, and spectral and voice perturbation measurements, this study seeks to fill a current gap in the vocal dose literature, namely, the exploration of potential relationships between vocal dose and real and perceived changes in voice quality.

Purpose Statement and Research Questions

The purpose of this study is to assess the voice use, voice quality, and perceived singing voice function of traditional age college/university singing students (N = 19), ages 18-24 years, enrolled in both voice lessons and choir, through (a) measurements of vocal dose and voice quality, collected over three full days of ambulatory monitoring and disaggregated by activity, with an unfiltered neck accelerometer signal acquired with the Sonovox AB VoxLog portable voice analyzer collar; (b) measurements of voice quality during singing and speaking vocal tasks acquired at three different times of day by both the contact accelerometer and the acoustic microphone included in the VoxLog collar; and (c) multiple applications of the Evaluation of the Ability to Sing Easily (EASE) questionnaire about perceived singing voice function.

The following research questions guide this investigation:

1. Are there statistically significant relationships between each of four measures of student vocal dose (phonation percentage, dose time, cycle dose, and distance dose) and each of ten measures of voice quality (F_0, $P_{0,}$ dB SPL, LTAS slope, alpha ratio, dB SPL 1-3 kHz, pitch strength, shimmer, jitter, and harmonic-to-noise ratio) acquired with the VoxLog collar's unfiltered accelerometer signal (a) over three full days of ambulatory monitoring and (b) between three types of activities (non-singing, choral singing, and solo singing)?

2. Are there statistically significant differences across time in each of ten measures of voice quality (F_0, $P_{0,}$ dB SPL, LTAS slope, alpha ratio, dB SPL 1-3 kHz, pitch strength, shimmer, jitter, and harmonic-to-noise ratio) acquired with the VoxLog collar's acoustic neck microphone (a) between the mean morning, afternoon, and evening measurements of singing and speaking vocal tasks and (b) between a baseline reading of speaking and singing vocal tasks and mean readings of these vocal tasks acquired during three days of monitoring?

3. What do participants' scores on the validated Ability to Sing Easily (EASE) questionnaire suggest about their perceptions of voice function during the course of this study?

4. Are there statistically significant relationships among each of four measures of participants' vocal dose over three days, each of ten measures of voice quality acquired through vocal tasks, EASE scores, participant sex, age, and amount/types of singing experience?

5. To what extent do bio-acoustic accelerometer voice source data acquired from participants in this study predict participants' acoustic source filter measures of voice quality?

For a complete list of sub-research questions, see Appendix F.

Definitions

Fundamental frequency (F_0) describes the rate at which the vocal folds vibrate, measured in Hz. It is the measure of the lowest frequency in the harmonic spectrum and it is perceived as pitch.

Perceived Pitch (P_0) is another measure that describes the rate at which the vocal folds vibrate, but it does so by analyzing the entire harmonic spectrum (in addition to the fundamental frequency) to determine the pitch that would be perceived by the listener.

Phonation time dose (Dt) refers to the cumulative duration of time (hh:mm:ss) or the percentage of time the vocal folds have actually touched in a given period.

A **vibratory cycle** is one complete sequence of opening and closing of the vocal folds.

Cycle dose (Dc) refers to the accumulated number of vibratory cycles in a particular time period.

Sound pressure level (dB SPL) is a measure of vocal intensity measured in dB. It is measured by the following formula: $SPL=20\ \log_{10}P/P_0 dB$ where P_0 is the standard reference air pressure (Titze, 2000). Distance of the sound level meter from the sound source can affect SPL measurements. SPL can be estimated from the accelerometer using a calibration process (Švec, Titze, & Popolo, 2005).

Distance dose (Dd). Researchers at the National Center for Voice and Speech coined the term “distance dose” (Dd) (Titze, Švec, & Popolo, 2003). This measurement combines the factors of phonation time, F_0, and phonation sound pressure level to estimate the total accumulated distance the vocal folds might "travel" over a period of time, calculating the total excursion of the vocal folds in each complete vibratory cycle. The following formula is used to calculate Dd:

$$D_d = 4\int_0^{t_p} k_v \, \mathrm{AF}_0 \, dt \quad \text{meters.}$$

Long-term Average Spectrum (LTAS) is an established method of measuring the energy of vocal resonance as a function of spectral frequencies by observing the mean intensity characteristics of the voice spectrum over time. LTAS has most often been used to analyze the resonant quality of vowels. The declination rate of the spectral slope, however, is largely dependent on the intensity of the signal produced by the glottal source. The spectral slope influences the timbre of the sound, with a smaller slope containing more high frequencies that create a more brilliant, “brassy” sound and a larger slope creating a lighter, “fluty” sound (Titze, 2000, p. 131). Thus, measurement of LTAS with an accelerometer that acquires only the vibrations of the glottal source will give some indication of the spectral declination rate, the vocal quality, and the efficiency with which the sound is being produced. This method of acquiring spectral measures from an accelerometer to evaluate voice quality and efficiency has recently been proposed and employed by Hillman, Zanartu, Ghassemi, Mehta, Van Stan and Cheyne (2013).

Alpha ratio is a measure of the spectral balance in LTAS. It is defined as the ratio of energy above and below 1000Hz. As it is a measure of vocal intensity, alpha ratio is often expressed in dB.

dB SPL 1-3 kHz is a measure of the total sound pressure level in the 1000-3125 Hz frequency band.

Pitch strength is a quantitative interpretation of the strength of the pitch sensation created by a complex tone, measured as a percentage. The higher the pitch strength, the more tonal the sound is judged. Perceptually, a sound with high pitch strength is perceived as a “clean” tone, while a “gravely” sound has low pitch strength (Camacho, 2012). Pitch strength is a measure of voice clarity.

Harmonic-to-Noise Ratio (HNR) is a measure of the ratio of periodic sound to non-periodic sound (noise) in vocal sound (Yumoto, Gould, & Baer, 1982). Measured in dB, an HNR of 0 dB would indicate equal parts harmonics and noise. HNR is also a measure of voice clarity.

Jitter is a measure of short-term (cycle-to-cycle) fundamental frequency variability in the voice. A descriptive term of voice perturbation, jitter does not have a universal physical definition (Titze, 2000). For the purposes of this study, PRAAT’s measure of jitter (Boersma & Weenink, 2014) will be employed: “This is the average absolute difference between consecutive periods, divided by the average period. MDVP calls this parameter *Jitt* and gives 1.040% as a threshold for pathology” (“Voice 2. Jitter,” para. 3). Jitter is expressed in percentages.

Shimmer is a measure of short-term (cycle-to-cycle) amplitude variability in the voice. A descriptive term of voice perturbation, shimmer does not have a universal physical definition (Titze, 2000). For the purposes of this study, PRAAT’s measure of shimmer (local) will be employed: “This is the average absolute difference between the amplitude of consecutive periods, divided by the average amplitude. MDVP calls this parameter *Shim*, and gives 3.810% as a threshold for pathology” (Boersma & Weenink, 2014, "Voice 3. Shimmer," para. 2).

The term **bioacoustic** as used in this investigation describes measurements of voice quality data acquired through the accelerometer contact transducer of the VoxLog collar, which measures vibration of the skin rather than through an acoustic microphone. These bioacoustic measures of voice perturbation and spectral energy will refer to measurements of glottal source vibrations that are traditionally acquired as acoustic source/filter voicing measurements. As such, bioacoustic readings of spectral measures, while valuable as measures of glottal source power, cannot be compared directly to spectral data acquired with an acoustic microphone that measures the sound filtered by the vocal tract. An advantage of bioacoustic measures is that they isolate the vibrations of the glottal source and are only minimally susceptible to the influence of ambient sound. A limitation of a contact transducer placed on the neck may be that persons may register vibrations produced by the glottal source differently due to different neck characteristics (thickness, muscle mass, fatty tissue). However, individual calibrations should compensate for any differences in signal strength, allowing for direct comparisons between individuals (Cheyne, 2002; Švec et al., 2005).

CHAPTER 2

Review of Literature

This chapter reviews the empirical studies that have been completed to date with respect to three overarching, non-invasive approaches to the assessment of vocal loading on voice efficiency and function: (a) acoustic measures employed to assess the effect of vocal load on speaking and singing voice quality, (b) validated measures of self-perceived voice quality, and (c) field studies of voice use, including perceptual studies and dosimeter studies of vocal dose. The section on vocal dose studies includes an outline of the development of ambulatory phonation dosimeters to date. These studies do not analyze the underlying physiological causes of vocal fatigue, nor do they involve a direct physiological analysis of the vocal folds or the musculature involved in vocalization. Rather they examine, through measurements of the acoustic and perceptual changes resulting from voice use over time, relationships between voice use and voice quality.

Acoustic Measurements of Voice Quality

Numerous studies analyzing the effect of vocal load through measurements of acoustic quality have been completed, nearly all of them in controlled laboratory situations. The results of these acoustic analyses to date have revealed few, if any, strong correlations between acoustic changes and vocal dose, muscular activity as a result of vocal loading, or complaints of vocal fatigue (Boucher, 2008; Boucher & Ayad, 2010; Chang, 2000; Eustace, Stemple, & Lee, 1996; Hunter & Titze, 2009; Lehto, Laaksonen, Vilkman, & Alku, 2006, 2008). Boucher (2008) has noted that “cross-study comparisons may be impractical because tasks have involved not only varying pitch and loudness but have also extended from 20 min to several days” (p. 1162) .

Fundamental Frequency (F_0). Normative adult speaking values of F_0 are 180-250 Hz for females and 100-150 Hz for males (Colton, 2006). No single universally accepted method for extracting F_0 from recorded sound has yet emerged. Various algorithms have been developed over the last several decades, all of which have resulted in slightly differing F_0 readings (Bagshaw, Hiller & Jack, 1993; Camacho, 2012; Camacho & Harris, 2008; Gerhard, 2003; Qiu, Yang & Ko, 2004; Sun, 2000; Rabiner, Cheng, Rosenberg & McGonegal, 1976). Several studies have compared these methods and provided comparison tables of gross error (Bagshaw, 1993; Camacho & Harris, 2008; Cheveigne, 2002; Gerhard, 2003). PRAAT's cross-correlation algorithm for F_0 extraction was found to have a gross error of 2.4% when measured against three speech and voice databases (Camacho & Harris, 2008). It should be noted that these studies analyzed a limited frequecy range usually focused around speech rather than the much wider frequency range employed in singing.

Regardless of collection methods, multiple studies have found that F_0 tends to increase both after significant periods of vocal loading and throughout the day (Artkoski, Tommila, & Laukkanen, 2002; Jonsdottir, Laukkanen, & Siikki, 2003; Laukkanen, Ilomäki, Leppänen, & Vilkman, 2008; Laukkanen et al., 2004; Lehto et al., 2006, 2008; L. Rantala, & Vilkman, E., 1999; L. Rantala, Vilkman, & Bloigu, 2002; Remacle, Finck, Roche, & Morsomme, 2012; Sisakun, 2000; Södersten, Granqvist, Hammarberg, & Szabo, 2002; Stemple, Stanley, & Lee, 1995; Vilkman, Lauri, Alku, Sala, & Sihvo, 1999). Higher F_0 was also found among teachers with multiple chronic voice complaints (L. Rantala, & Vilkman, E., 1999). This increase in F_0 may have resulted from increased muscular activity and tension that occurred following a fatiguing loading activity. On the other hand, Boucher and Ayad (2010) found that individual variations in F_0 did not consistently reflect measured muscular fatigue in laryngeal structures.

Eustace, Stemple, and Lee (1996) found no connection between F_0 and chronic complaints of vocal fatigue (N = 88).

Increases in F_0 have been linked to the SPL of voicing. Gramming, Sundberg, Ternström, Leanderson and Perkins (1988) found that mean pitch increased by about one-half semitone per one dB increase in SPL. The authors suggested that the increase was likely a passive result of the increased subglottal pressure needed for increased volume. Vogel, Fletcher, Snyder, Fredrickson and Maruff, (2011) found that the Lombard effect, the tendency of voices to increase in dB SPL relative to the level of ambient sound, significantly raised F_0 as well as SPL.

Perceived Pitch (P_0). P_0 is a measure for which no published studies yet exist. P_0 is based on a pitch extraction algorithm entitled Audswipe which was recently developed by Camacho (2012). Instead of identifying only the fundamental frequency, Audswipe examines the entire harmonic spectrum to determine the "perceived pitch". It does so by flattening the harmonic spectrum, grouping frequencies the way the ear does, and matching small segments to sawtooth waveforms of various frequencies. In testing at an F_0 bandwidth of 50-500 Hz, Audswipe out-performed all other pitch extraction algorithms on both telephone quality databases and in recordings of musical instruments. Thus, while it is almost identical to F_0, P_0 is potentially a more realistic and robust pitch estimator (personal communication, E. Hunter, April 5, 2014), especially for the analysis of singers through an accelerometer signal.

Sound Pressure Level (dB SPL). The effects of vocal loading on dB SPL have been examined by multiple studies using various methodologies of data collection over different lengths of time and in different environments. Some studies have found a rise in intensity after periods of vocal loading (Jonsdottir et al., 2003; Laukkanen et al., 2008; Laukkanen et al., 2004; Vilkman et al., 1999) or simply later hours of a day over a full day of observation (Artkoski et al., 2002). Rantala and Vilkman (1999) found that teachers with more voice complaints increased their SPL level early in the day. This increase in SPL also improved their voice quality by reducing voice perturbation levels, but the authors speculated that due to fatigue, they could not maintain this SPL increase later in the day. Brockmann, Storck, Carding, amd Drinnan (2008) found that men tend to speak with a higher dB SPL than women overall.

Shimmer, jitter, and harmonic-to-noise ratio. Shimmer, jitter, and harmonic-to-noise ratio have long been employed as acoustic perturbation measures of voice quality and thus as potential indicators of vocal efficiency. Colton (2006) has commented that all voices have some naturally occurring variations in perturbation, but attention should be paid when these measurements exceed normal boundaries.

Brockmann, Storck, Carding, and Drinnan (2008, 2011) published two recent studies on shimmer and jitter measurements. They found limitations in the two measures over the years resulting in part from uneven analysis methods, with different methods of calculation and differences in reported normative values, even among the same calculation types. They found that shimmer and jitter readings varied based on vowel, gender, F_0 and dB SPL. dB SPL was found to be the most significant factor, with shimmer and jitter significantly increasing with decreasing voice loudness among health adults aged 20-40 years.

Studies have found conflicting results when examining perturbation measures following vocal loading tasks. Jitter and shimmer decreased following vocal loading tasks in multiple studies (Laukkanen et al., 2008; Sisakun, 2000; Stemple et al., 1995). Similarly, Rantala, and Vilkman (1999) also found lower shimmer and jitter values in field recordings of teachers with voice complaints than among teachers without complaints. As decreased vocal efficiency would seem to indicate higher voice perturbation readings, these results were unexpected. However, multiple researchers have speculated that the decreased perturbation measures may have resulted from compensatory muscle tension, which, though potentially hyperfunctional, actually suppressed voice perturbation (Boucher, 2008; Laukkanen et al., 2008; Rantala, & Vilkman, 1999). In a study employing electromyography to laryngeal musculature, Boucher and Ayad (2010) found that the voice demonstrated a brief period of increased tremor at the point of muscular fatigue at which the lateral crico-arytenoid muscles tired and surrounding compensatory musculature was recruited, after which the voice acoustically returned to its prior state. Muscular compensation such as this may have caused the voice to continue creating an acoustically indiscernible signal even though the individual felt a sensation of fatigue.

In contrast, Scherer et al. (1987) found that jitter and shimmer were significantly higher in a trained voice user following a vocal loading task, but these changes did not occur with an untrained individual. Stemple et al. (1995) found no significantly abnormal jitter after prolonged voice use, and Eustace et al. (1996) found no abnormalities in jitter among chronically fatigued patients. Cho, Yin, Park, and Park (2011) found that evidence of mental fatigue was a significant indicator of perturbation measures in men, including jitter, shimmer and HNR, but that perturbation measures were not indicative of mental fatigue in women or overall physical fatigue for either men or women ($N = 73$). Sisakun (2000) found slightly increased HNR in a study of vocal fatigue among undergraduate student singers ($N = 15$) after a vocal fatiguing task of 45 minutes of singing. Acoustic perturbation measures have not yet received attention in ambulatory field studies of voice use, where they could be measured at the vocal source by an accelerometer transducer.

Pitch strength. Pitch strength is a quantitative interpretation of the strength of the pitch sensation created by a complex tone. The measure was developed by Fastl and Zwickle (2007) and is currently being employed by researchers to measure disordered voice severity (Camacho, 2012; personal communication, Eric Hunter, May 23, 2014). Measured as a percentage, the higher the pitch strength, the more tonal the sound is perceived. Thus, a tone with high pitch strength might be perceived as "clean" while a tone with low pitch strength might be perceived as "rough" or "gravely."

Long-term average spectrum, alpha ratio, and dB SPL 1-3 kHz. Long-term average spectrum (LTAS) has become an established method of measuring voice quality by observing the mean intensity characteristics of the voice spectrum over time. Alpha ratio is a measure of the spectral balance in LTAS proposed by Frøkjaer-Jensen and Prytz (1976). The upper frequency level for the calculation of alpha ratio has varied between 5,000 and 10,000Hz. Because the measure divides the total intensity for high frequencies above 1000Hz by the total intensity for frequencies below 1000Hz, alpha ratio increases as the high frequency content of the sound increases. Krause and Braida (2004) suggested that measuring the total sound pressure level between 1000 Hz and 3125 Hz would give a good indication of vocal resonance (hereafter refered to as dB SPL 1-3 kHz). The declination rate of the spectral slope measured by LTAS and alpha ratio and the strength of the signal in the 1-3 kHz range are dependent on the intensity of the glottal source vibrations (Titze, 2000). Thus, while these measures have been used to examine resonance characteristics, it has been suggested that they may actually be a better measure of glottal source activity (Leino, 2009).

LTAS and alpha ratio have frequently been employed as measures of singing voice resonance. Different resonance strategies used for different styles of singing are readily identifiable through LTAS measures (Goodwin, 1980; D. G. Miller, 2008; Rossing, Sundberg & Ternstöm, 1986). The term "singer's formant" was established as a description of a spectral peak that occurs in the region of 3-5 kHz by combining the spectral power of the third, fourth, and fifth formants in classical singing. Rossing, Sundberg, and Ternström (1986) found that singers alter their resonance between choral and solo singing, amplifying the singer's formant when acting as soloists and amplifying F_0 when acting as choristers. The focus on F_0 in choral singing was judged to be a voice source effect.

Vocal warm-up exercises have been shown to positively affect resonance as measured by LTAS and alpha ratio in both speech and singing. Guzman, Angelo, Munoz, and Mayerhoff (2013) examined the effect of vocal function exercises on LTAS and alpha ratio in pop singers using PRAAT. The study found significant increases in alpha ratio immediately following the exercises, indicating a slower decline in the LTAS slope and improved vocal resonance. Leino, Laukkanen, and Radolf (2011) found an increase in harmonic activity surrounding the "actor's formant," the presence of a spectral peak between 3kHz and 4kHz, following 30 minutes of vocal exercises using strings of nasal syllables.

Several studies have found significant relationships between speaking voice quality and LTAS/alpha ratio. Mendoza, Valencia, Muñoz, and Trujillo (1996) found significant differences in the LTAS qualities of men and women, with women having greater aspiration noise (breathy quality), located in the spectral area of the third formant. Patel, Scherer, Sundberg and Björkner (2010) found that alpha ratio and LTAS were significantly affected by the emotion of the speaker. Kitzing (1986) examined LTAS and alpha ratio of four types of voice quality produced by non-dysphonic voices during continuous speech: normal/sonorous, leaky, strained, and soft. The study found small but significant differences between the sonorous and strained sounds, particularly in alpha ratio, the spectral slope inclination in the first formant range, and the ratio between the peak level of F_0 and the first formant region. It found stronger intra-individual comparisons than inter-individual ones.

Leino (2009) examined LTAS and dB SPL 1-3 kHz in the voices of 50 untrained male university students. After voice quality was rated by an expert panel and separated into groups of “good,” “intermediate,” and “poor,” LTAS examinations found that good and intermediate voices differed significantly from the poor voices with increased activity in the 1-3 kHz range and a peak in the 3-4 kHz range. There was a significant positive correlation between the voice ratings and alpha ratio. Sundberg and Nordenberg (2006) found a strong positive correlation between alpha ratio and vocal loudness. As in Kitzing’s study, there were differences between individuals, but alpha ratio could be predicted from the equivalent vocal sound level for an individual voice.

LTAS has also been shown to differ in dysphonic voices. Lowell, Colton, Kelly, and Hahn (2011) found significant differences in LTAS in terms of spectral mean, skewness, and kurtosi between dysphonic (N = 27*)* and non-dysphonic (N = 27*)* speakers. Lowell, Colton, Kelly, and Mizia (2013) also found that spectral- and cepstral-based measures were highly predictive of dysphonia severity. The spectral measures employed in this latter study compared low to high frequency distribution in the spectrum (above and below 4000 Hz), similar to alpha ratio.

Changes in LTAS measures and alpha ratio have been recorded throughout the day. Löfqvist and Mandersson (1987) found that LTAS changed at different times of day in days that involved vocal loading. Artkoski, Tommilla, and Laukkanen (2002) found similar changes in days without vocal loading. They examined 11 females and 10 males over a normal day without any vocal loading and found that alpha ratio was significantly higher for females and lower for males in the afternoon. Another laboratory vocal loading study among 24 females also found that alpha ratio rose during the day (Laukkanen et al., 2004). Vogel, Fletcher and Maruff (2010) found that alpha ratio increased over 24 hours of sustained wakefulness among 18 healthy adults, peaking at 22 hours with a magnitude of difference of 0.35 from the baseline reading.

Acoustic analysis methods. Various factors have affected the assessment of acoustic signals, including the quality of the recording equipment, the algorithms used, and the computer software employed in the analysis. Two commonly used analysis software programs are the Multi-Dimensional Voice Program (MDVP) included in the Computerized Speech Lab by KayPentax, and PRAAT, an open-source software acoustic analysis program available for free download on any PC (Boersma & Weenink, 2013). Although both programs are have become well accepted in the field of voice research, two recent studies found few statistically significant positive correlations between the two programs' analysis of voice perturbation measures, with MDVP consistently returning higher numbers than PRAAT. The primary reason for this difference was the different pitch extraction algorithms employed by the two programs. As a result, Maryn et al. suggested that no direct comparisons of perturbation measures should be made between studies using the different programs (Maryn, Corthals, De Bodt, Van Cauwenberge, & Deliyski, 2009; Oğuz, Kiliç, & Şafak, 2011). Deliyski, Shaw, Evans, & Vesselinov (2006) found that analysis software had the most prominent effect on perturbation measures, followed by sex and microphone type.

Other studies have examined the acceptable sampling rates necessary for reliable and valid analysis of acoustic voice quality. Deliyski, Shaw, and Evans (2005) found that a sampling rate of 26 kHz or above was recommended to avoid errors of less than 1% in voice quality measurements for MDVP and PRAAT, with a minimum sampling rate of 19 kHz required. This recommendation was in line with an earlier recommendation from NCVS of at least 20 kHz (Titze, 1994).

A technical challenge of voice dosimetry has been the analysis of long term files, which may include multiple gigabytes of data. Bäckström, Lehto, Alku, and Vilkman (2003) developed a method of surmounting this challenge through an automatic pre-segmentation process that analyzed up to five-minute audio segments at a time. The method classified all periods of the recording as silence, voiced speech or unvoiced speech. These researchers found that this method was robust and consistent with similar analyses of continuous speech.

Bioacoustic measures with an accelerometer. Taking bioacoustic signals from an accelerometer transducer that measures skin vibration on the neck has been suggested as a means to measure glottal source characteristics, including glottal air flow, maximum flow declination rate, cycle quotients, and spectral measures (Cheyne, 2002, 2006; Hillman et al., 2013; Zanartu, 2010; Zanartu et al., 2009). Ghassemi et al. (2014) used multiple parameters extracted from an ambulatory accelerometer signal worn over seven days to correctly distinguish between participants with and without vocal nodules in 22 out of 24 cases. Hillman et al. (2013) described a large federally funded study (N = 400) currently underway that has been employing these measures by recording unfiltered neck accelerometer signals on smartphones. Hunter (personal communication, July 3, 2013) has suggested that the accelerometer glottal source measurements of traditional acoustic measures such as LTAS, alpha ratio, shimmer, jitter, and HNR could provide a more robust picture of vocal efficiency than the filtered sound. While the accelerometer does not measure the effect of vocal tract resonance on the glottal source signal, these measurements could be more robust in measuring glottal efficiency, in part because the accelerometer isolates the vocal sound in a field setting where other noise is present and in part because the above perturbation and spectral declination measures are more dependent on the vocal source than the filter. Notably, neck accelerometer-based voice quality measurements could not be compared to acoustic microphone readings, but simultaneously acquired accelerometer and acoustic microphone signals could be analyzed to determine if strong correlations between the two measurements exist.

Self-Perception of Voice Quality

Validated tools. Due to the difficulties in finding acoustic correlates of vocal fatigue, Hunter and Titze (2009) have suggested that perceptual-based methods may be "most feasible existing method to successfully track or quantify the effects of vocal loading events" (p. 451). Several validated surveys have been developed by researchers interested in learning about individuals' perception of voice quality. Jacobson (1997) developed the Voice Handicap Index (VHI) to assess the perception of the severity of a patient's voice disorder. The survey included 30 questions, with a higher score indicating a more severe handicap. Others (Rosen, Lee, Osborne, Zullo, & Murry, 2004) developed and independently validated (Arffa, Krishna, Gartner-Schmidt, & Rosen, 2012) a 10-question version of the VHI with normative values, the VHI-10.

Two studies applied the VHI to singers. Rosen (2000) compared singers (*n* = 106) to non-singers (*n* = 369) and found that singers scored significantly lower than non-singers, with classical singers scoring the lowest (Rosen, 2000). A recent study administered the VHI-10 to both medical students and musical theatre students found that the musical theatre students scored higher in the VHI-10 (indicating greater handicap), particularly in three items: voice strain, lack of clarity, and being upset about voice problems (Watson, Oakeshott, Kwame, & Rubin, 2013).

In order to better measure self-perceived handicap in singers, Cohen, et al. expanded on the VHI with the creation and validation of the Singing Voice Handicap Index (SVHI) (Cohen et al., 2007; Cohen, Witsell, Scearce, Vess, & Banka, 2008). The SVHI was based on the earlier Voice Handicap index and consisted of 36 statements found to be statistically reliable. Raw scores were scaled to range from zero to 100. In a pilot study testing the index, a control group of singers reporting no dysphonia (N = 129) had a median SVHI score of 22 versus a median score of 61 among singer-patients with a diagnosed vocal dysfunction.

Because the VHI and SVHI were originally designed for to test the severity of dysphonia among a population of persons with reported voice injuries, the need for a validated survey tool that measured perception of vocal efficiency and fatigue among non-dysphonic patients with greater precision became apparent (Phyland, Thibeault et al., 2013). Three recently validated tools designed to address this issue were the Vocal Fatigue Index (VFI), the Voice Fatigue Handicap Index (VFHI), and The Evaluation of Ability to Sing Easily (EASE) survey (Nanjundeswaran, 2013; Paolillo, 2012a, 2012b; Phyland, Pallant, et al., 2013).

EASE questionnaire. The Evaluation of the Ability to Sing Easily (EASE) questionnaire was recently validated as a clinical tool "to assess singer's perceptions of the current status of their [*sic*] singing voice" (Phyland, Pallant et al., 2013, p. 454). The EASE survey consisted of 20 questions in two 10 question subsections, the first subsection dealing with perceived physical symptoms of vocal fatigue and the second subsection dealing with perceived symptoms that would result from mucosal changes. The developers of the survey reported that "EASE may prove a useful tool to measure changes in the singing voice as indicators of the effect of vocal load. Furthermore, it may offer a valuable means for the prediction or screening of singers 'at risk' of developing voice disorders" (Phyland, Pallant et al., p. 461). The survey's focus on non-dysphonic singers, with subsections that deal separately with perceived symptoms of fatigue and perceived mucosal changes, made it ideally suited to the evaluating the effect of vocal load on developing singers.

Perceptual Field Studies of Voice Use

Studies that have measured self-perception of singer voice use and health have demonstrated that higher vocal doses do not necessarily correlate positively with a greater perception of vocal decline. A 1995 survey of singing teachers (*N* = 125) by Miller and Verdolini about self-perceived voice problems indicated that more estimated hours of singing per day corresponded to fewer current self-reported voice problems by a factor of three. In a large survey analyzing risk factors for voice problems in teachers (*N* = 1878), Kooijman et al. (2006) also found that voice load and environment were less important risk factors for voice problems than were physical and psycho-emotional factors.

Other studies have used survey tools to learn about singer voice use. Barnes-Burroughs and Rodriguez (2012) surveyed the perceived vocal health and hygiene of 596 members of the National Association of Teachers of Singing (NATS) who identified themselves as teaching performers. The teachers estimated that during non-performance periods they spent an average of 5.5 hours speaking and 2 hours singing each day, while during performance periods they spent 4.5 hours speaking and 2.5 hour singing. While 95% of participants warmed up before performances, only 52% of teachers reported that they typically warmed-up before teaching and only 16% engaged in cool-down exercises following performance. It was suggested that increased vocal hygiene training at the pre-service level could help teaching performers become more successful at maintaining vocal health.

Timmermans et al. (2002) found that future elite vocal users (*n* = 86 students at a high school for audiovisual communication in Brussels, Belgium) may not have taken care of their voices as well as a control group (*n* = 68). The study found that these future voice professionals scored significantly worse than a control group characterized by no vocal complaints on multiple measures of vocal health, including the dysphonia severity index (DSI) and the VHI. The future professional group also demonstrated worse vocal hygiene than the control group, including higher incidences of smoking (57%), eating late meals 3 or more times each week (30%), and vocal abuse, including yelling, shouting, etc. (19%). The study concluded that more training in proper voice use and vocal hygiene was necessary for the health of this group of future voice professionals, but a follow-up study (Timmermans et al., 2005) found that 9 months of training had not effectively caused students to change their vocal hygiene habits.

Bowers and Daugherty (2008) examined self-reports of high school students at a summer choral camp. Participants (*N* = 141) were surveyed prior to and following an intensive week of singing (up to eight rehearsal hours per day) to see if students perceived any changes to their vocal production. In questions regarding 12 aspects of vocal health, students reported deterioration in six categories, including hoarseness, tiredness, dryness, throat pain when singing, straining to sing, and more effort needed to sing or talk. Students also reported a significant increase in "vocal difficulty" between the pre- and post-tests. However, there was no significant change from the pre- to post- test regarding the question "I have taken good care of my voice this past week."

Tepe et al. (2002) examined incidences of vocal problems among choir singers ages 25 years and younger who responded to a survey about vocal health and vocal hygiene (*N* = 129, a 22% return rate of distributed surveys). More than half of the respondents indicated that they had experienced vocal difficulty and one third-reported “over-singing.” In an unexpected result, students who reported having taken voice lessons were no less likely to report vocal difficulties than students who had not.

Phyland, Thibeault, et al. (2013) examined working music theatre performers without reported vocal problems through focus groups (*n*= 49) and written surveys (*n*= 36). The survey found differences in opinion regarding the vocal effects of performing 8 shows per week, some positive and some negative. The direction of change was affected by the vocal demands of the show and role, scheduling, season length, and theatre acoustics. Overall trends included greater perceived vocal fatigue on the first and last day of the working week and regular intra-individual variability in vocal fatigue and perceived effort.

Voice Dosimeter Studies of Voice Use

Ambulatory monitoring using acoustic microphones. Research publications have described devices for monitoring voice use since as early as 1974 (Cheyne, Hanson, Genereux, Stevens, & Hillman, 2003). Various methods were developed to estimate voice use through audio recording. Many of these studies focused on teachers and found teacher Dt to be 15%-40% (Masuda, 1993; L. Rantala, Haataja, K., Vilkman, E., & Körkkö, P., 1994; L. Rantala et al., 2002; Södersten et al., 2002). Other methods of ambulatory monitoring, including the recording of voicing time and dB SPL in the field through the sound level meters, were explored (Airo, 2000).

The use of an electrically activated recorder (EAR) has been employed for several studies of voice use. In a study by Mehl, Pennebaker, Crow, Dabbs, & Price (2001), a recorder was activated for 30s every 12 minutes, all captured words were transcribed, and the number of words per day was estimated. A large EAR study (*N* = 396*)* found that women spoke on average

16,215 (*SD* = 7301) words each day and men 15,669 (*SD* = 8633) words over an average of 17 waking hours (M. Mehl, Vazire, S., Ramírez-Esparza, N., Slatcher, R., & Pennebaker, J., 2007). The method was recently adapted as an iTunes app for use on iPods or iPhones (M. Mehl, 2011).

Dosimetry using accelerometer transducers. The ambulatory phonation dosimeter, also known as a “vocal accumulator” or “voice dosimeter,” was developed in the early 2000s. Voice dosimeters were created to measure vocal dose, defined as vocal fold tissue exposure to vibration over time (Hillman, 2004; Švec, Popolo, & Titze, 2003; Titze et al., 2003). Rather than relying on acoustic audio recording methods, these devices used an accelerometer transducer to record skin vibrations in the neck. In this way, the monitored individual’s phonation activities were largely isolated from ambient sounds. As acoustic sound pressure levels could not be acquired from skin acceleration levels, a method for calibrating the accelerometer signal with an acoustic signal was developed to estimate sound pressure levels.

Safe levels of distance dose. Titze, Švec, and Popolo (2003) refined measures for determining excessive levels of distance dose by quantifying the safe continuous travel limit of the vocal folds. Comparing the limits of exposure to industrial calculations for hand-transmitted vibrations, they calculated a safety distance dose limit of 520m, which would be reached in 17 minutes given an average of 0.5m per second of continuous phonation. However, this calculation of vocal dose did not take into account the fact that singers rest quite frequently during all phonation or the complex make-up of the vocal folds. The authors hypothesized that this brief recovery time and the construction of the vocal folds allowed the voice to very significantly extend healthy phonation periods.

Reliability of accelerometer-based dosimeters. Several studies verified the reliability of this new dosimeter technology in measuring phonation data (Cheyne et al., 2003; Hillman, Heaton, Masaki, Zeitels, & Cheyne, 2006; Švec et al., 2003; Švec et al., 2005; Szabo, Hammarberg, Granqvist, & Södersten, 2003; Szabo, Hammarberg, Håkansson, & Södersten, 2001). Popolo, Švec, and Titze (2005) found that harmonic content acquired by the accelerometer was more conducive to the extraction of F_0 than an acoustic microphone. Švec, Titze, and Popolo (2004) also found that mean SPL from voiced speech could be predicted by a skin accelerometer with accuracy of better than ±2.8 dB.

A comparison of two vocal dosimeter collection methods, one employing an accelerometer and the other binaural acoustic microphones, demonstrated that accelerometers were more robust at detecting phonation activity than even the most robust airborne measures. The study found that the accelerometer method had only a 0.5% probability of false voicing detection (Lindstrom, Ren, Li, & Waye, 2009). While the accelerometer was mildly sensitive to body movements, the employment of a high bandpass filter eliminated 99.9% of these false positives.

A similar study (Zanartu et al., 2009) compared two different types of accelerometer transducers with an acoustic microphone. The study found that all methods displayed some sensitivity to airborne acoustics (as opposed to the desired bio-acoustic skin vibration signal) but that an understanding of the noise floor produced was important in processing to extract voice activity only in the data analysis and that an accelerometer produced by Knowles was the preferred choice for voicing measurements. The study results estimated that dB SPL was typically ~1 dB lower at the sternal notch than at 30cm from the mouth. The accelerometer specifications provided by Knowles Acoustics for its BU-1771 accelerometer, the model used in the VoxLog dosimeter collar, indicated sensitivity tolerance of +/- 4.5dB @ 1000 Hz and declining sensitivity in dB relative to 1.0v/g acceleration at frequencies above 2.5 kHz ("BU Series Accelerometers," 2013).

Mehta, Woodbury et al. (2012) conducted a pilot study (*N* = 10) to investigate the length of time ambulatory monitoring must occur in order to accurately estimate long-term average vocal dose measures. Using KayPentax APMs, the study found that F_0 error dropped to 1% after 12 hours of monitoring, and SPL error dropped to1% after 20 hours of monitoring. Errors for phonation time, cycle dose, and distance dose, on the other hand, needed at least 26 hours of monitoring for average errors to drop below 10%. The study recommended that future voice dosimetry should involve the recording of raw, rather than sampled, accelerometer signals.

Van Stan, Gustafsson, Schalling, and Hillman (2014) made a direct comparison of three commercially produced ambulatory dosimeter devices, the VoxLog, the KayPentax Ambulatory Phonation Monitor (APM) and the Vocalog. The researchers recorded a 90-minute lecture that was also recorded simultaneously using a Smart-phone system. The study found that each device had benefits and limitations with similar results for most dose measures, but that the VocaLog overestimated phonation time.

Participant response to dosimeter devices. Nix, Švec, Laukkanen, and Titze (2007) provided an outline of various protocol challenges for dosimeter use, including discussions of privacy concerns and recruitment and retention of participants. A major concern has been that participants could alter their vocal behavior due to the presence of a recording dosimeter. Studies have shown that participant behavior may be affected by the presence of an ambulatory monitoring device (Hermida et al., 2002). Hunter (2012) surveyed 14 participants in a teacher study using NCVS dosimeters with 16 questions about their response to the devices. The study found the participants evenly divided in their opinion of whether the presence of the dosimeter affected their voice use, while nine of the fourteen reported that they became unaware of the device at some point. All reported that others noticed the device. The size and obtrusiveness of wires of this dosimeter--carried in a visible waist pack--and irritation from adhesive used to attach the accelerometers to the participant's neck were considered to be negative aspects of the study, but all reported an overall positive experience. All but one of the participants said they would recommend participation in the study to a friend. Further study of how awareness of the device affects vocal behavior was recommended, as well as the use of less obtrusive devices.

Review of ambulatory voice dosimeter studies. Studies employing accelerometer-based dosimeters to date have begun to build a body of data about typical voice use in different situations.

Teachers. Numerous studies have indicated that teachers are among the population with the highest risk of voice disorders (Assunção, Bassi, de Medeiros, de Souza Rodrigues, & Gama, 2012; Munier & Kinsella, 2008; Roy, Merrill, Thibeault, Gray, & Smith, 2004; Russell, Oates, & Greenwood, 1998; Vilkman, 2004; Williams, 2012). As a result, teacher voice use has been the focus of numerous dosimeter studies to date (Nacci, 2013). The largest study, conducted by the National Center for Voice and Speech (NCVS), monitored 57 teachers for two weeks each with dosimeters constructed by NCVS (Hunter & Titze, 2010; Titze, 2007; Titze, Hunter, & Švec, 2007). The participants wore the dosimeters from 9:00-3:00 on weekdays and from 4:00-10:00 on weekends for comparisons to non-occupational periods. The study (Hunter & Titze, 2010) made the following observations:

> (1) Similar to previous studies, occupational voicing percentage per hour is more than twice that of nonoccupational voicing; (2) teachers experienced a wide range of occupational voicing percentages per hour (30 ± 11% per hr); (3) average occupational voice was about 1 dB SPL louder than the nonoccupational voice and remained constant throughout the day; (4) occupational voice exhibited an increased pitch and trended

> upward throughout the day; and (5) some apparent gender differences were shown (p. 862).

As a part of this study, 10 participating teachers completed a short series of vocal tasks every two hours. Using analysis of these tasks as well as perceptual ratings form expert clinicians and the teachers themselves, researchers found that self-evaluation of inability to produce soft voice had strong potential as an indicator of vocal fatigue (Halpern, Spielman, Hunter, & Titze, 2009).

Bottalico and Astolfi investigated 40 teachers in six schools over a total of 73 working days (2012). The schools were divided into two groups based on the type of classroom reverberation, with the first group averaging 1.13s and the second averaging 0.79s. Average occupational voicing time was similar to the NCVS study, with 25.9% voicing for females and 25.1% for males. The vocal doses were the same for both groups of classrooms, but subjective surveys revealed a less favorable perceived acoustic environment in the more live set of rooms. There was a significant increase in mean SPL, about 5 dB, from morning to afternoon. Data also indicated the presence of the Lombard effect, with a 0.72dB increase in speech level (measured at a distance of 1m) and a 1Hz increase per 1dB increase in background noise.

Franca (2013) studied 11 female student teachers over the course of a semester using KayPentax APMs. The participants wore APMs for one working day (8:30am-3:30pm) at three different points, the beginning, midterm and end, of the semester. Monitoring days were coupled with acoustic analysis in a laboratory setting and completion of pre- and post-questionnaires about voice use and health. Examination of the acoustic data in the voice lab revealed significant increases in F_0, relative average perturbation, shimmer, and HNR from the beginning to middle of the semester. Dosimeter data showed a significant SPL increase in the classroom, though there was not a significant SPL change in the laboratory, indicating either increased vocal effort in the natural classroom setting as compared to the laboratory or APM SPL calibration issues. Questionnaires revealed that a majority of the participants frequently use their voice with excessive effort and that 60% seldom used preventative techniques to save their voices.

Music Teachers. In a study of vocal music teachers, Daugherty, Bowers, Garnett, Reussner, Cannady, and Morris (2009) found that these teachers spoke or sang during 60.34% to 72.58% of classroom time and vocalized more than a math teacher in part because they sang at the same time as their students, from 16.76% to 38.84% of class time. In a similar study of elementary music teachers, Morrow and Connor (Morrow, 2009; Morrow & Connor, 2011a) found that music teacher vocal doses were significantly higher than that of other classroom teachers. A follow-up dosimeter study (Morrow & Connor, 2011b) and a similar case study by Gaskill, O'Brien, and Tinter (2012) found that teacher amplification decreased overall vocal doses and was thus effective in reducing the potential for vocal problems.

In three case studies (Schloneger, 2012a, 2012b; Wingate, 2007) using KayPentax Ambulatory Phonation Monitors, studio voice teacher Dt was comparable to that of classroom teachers, both in terms of occupational and non-occupational voice. In one of the studies by Schloneger (2012a), two teachers used their voices more during teaching hours over the course of a week than they had estimated in a survey prior to the phonation monitoring.

Children. Hunter, Halpern, and Spielman (2012) examined the voice use of a child through four full days of voice dosimetry. The study found that the child had significantly different F_0 and dB SPL levels across four different speaking environments – free play, preschool, home, and time with adults, with free play having more variability in these measures and preschool having higher F_0 mean and SPL than in preschool and adult time.

Student vocalists. Voice dosimeter studies have examined voice use among student vocalists. Daugherty, Manternach, and Price (2011) combined perceptual and dosimeter data to examine student voice use during a 3-day all-state high school chorus event in a Midwestern state, including daily surveys of the student singers (N = 256) and vocal dose data from KayPentax APM units worn by two students over three days. The study found significant deteriorating changes in self-reporting of 5 of 7 vocal health indicators surveyed (tired voice, hoarseness, comfortable access to higher range, strained singing, and throat pain) and the question “right now, the overall quality of my singing voice is..,” yet almost 80% of the students believed they had “taken good care” of their voices. Both students wearing the APM units recorded Dt outside of rehearsal that approximated Dt in rehearsal. The female participant had a 20.92% rehearsal Dt compared to a 17.96% non-rehearsal Dt and a 17.14% Dt in pre/post event periods. The male participant had a 24.34% rehearsal Dt, a 19.88% non-rehearsal Dt, and a 5.73% Dt in the pre/post event periods. The authors suggested that proactive voice care education would be helpful in preventing vocal problems among young singers.

Several studies used voice dosimeters to analyze the habits of college and university voice students. Austin and Hunter (2009) used dosimeters to follow eight vocal performance majors enrolled at the University of North Texas during waking hours over the course of a typical five-day week. Students participated in choral and opera rehearsals, voice lessons, and regular daily activities. Vocal Dt ranged from 9.92% to 26.00%. Average Dd ranged from 0.65 to 1.37 meters per second, with total Dd over five days ranging from 7.4 miles (11906 meters) to 26.0 miles (37007 meters).

Manternach (2011a, 2011b) examined the vocal habits of eight pre-service music educators, six vocalists and two instrumentalists, over a “typical” seven-day week during the semester. Participant Dt ranged from 6.87% to 13.52% overall and from 5.93% to 16.93% during school activities. Mean Dt during non-school hours was 9.32%. Dt percentage averages were highest during voice lessons (38.51%), voice practice (34.54%), and choral rehearsals (30.33%) and the lowest during non-music classes (3.21%). Accompanying perceptual surveys found that number of sleep hours had a positive correlation with self-reported voice quality and that extroversion levels did not correlate to Dt.

Schloneger (2010) analyzed two undergraduate women during an intensive rehearsal week in which both students were involved during nearly 40 rehearsal hours. Dt was 13.76%-18.53% during the intensive week as compared to 6.94%-10.86% during baseline weekend days. One student, who tested as an extrovert on the Keirsay Temperament Sorter, accrued 17.3% Dt outside of rehearsal during the intensive week, while the other, an introvert, accrued 8.92% phonation time outside of rehearsal. Both students reported some declines in their perception of vocal health over the course of the intensive week, but the introvert reported a decline of 26.4 points out of 100 on the Singing Voice Handicap Index while the extrovert, though she accrued a higher vocal dose by all measures, reported an SVHI improvement of 4.9 points. The results of this case study suggested that these students could have benefitted from voice care education and that more research is needed to examine the ways in which high vocal doses have varying effects on the vocal health of different individuals.

Schloneger (2011) also completed a study of two graduate female singers and studio teaching assistants during an intensive opera rehearsal week. The singers had a Dt of 11.79%-14.13% during their intensive rehearsal week. In contrast to the undergraduates observed in the above study, these more experienced graduate participants phonated less in non-rehearsal time during the intensive rehearsal week (5.90% - 7.49%) than they did during non-rehearsal time in four baseline monitoring days (8.91% - 9.61%).

Gaskill, Cowgill, and Tinter (2013) completed a similar pair of studies with graduate and undergraduate voice students. They examined six graduate vocalists, four females and two males, over a five-day week with KayPentax APMs. The dosimetry measurements were coupled with pre- and post-laryngoscopic imaging, applications of the SVHI, and acoustic voice analysis of vocal tasks, including F_0, shimmer, jitter, HNR, and pitch glides to determine highest and lowest pitch. There were no significant changes in the acoustic readings or (Gaskill, Cowgill, & O'Brien, 2013) the laryngeal findings from the first to the fifth day. Overall Dt ranged from 10.26% to 16.03%, with singing Dt ranging from 16.17% to 31.36% and other phonation Dt ranging from 5.92% to 11.96%. Dd ranged from about 3000-8000m per day. One of the six singers exhibited significantly higher dose measures than the others and also had a higher SVHI score and a loss of two semitones in range from the first to the fifth day. It was suggested that this finding represents the effectiveness of the study method in identifying individuals who need to alter their vocal habits in order to maintain vocal health.

Another dosimeter study of six undergraduate music majors analyzed two students majoring in vocal performance, two music education majors, and two musical theater majors, with a soprano and a tenor representing each pair (Gaskill, Cowgill, & O'Brien, 2013). These undergraduates had an average overall Dt of 12.91%, a mean singing Dt of 23.07%, a mean non-singing Dt 10.31%, and a mean daily Dd of 5403m. One music education tenor experienced perceptual vocal decline and an increase in jitter 36 hours after an intensive 3.5 hour rehearsal in which he phonated 41 minutes with an average SPL of 92 dB and an F_0 of 212 Hz. Similar to the results in Schloneger’s two studies (2010, 2011), the undergraduates had higher overall and non-singing Dt than the graduates, while the graduates had a higher singing Dt, suggesting that experienced graduate students were more conscious of voice care.

Recent developments in voice dosimetry. Prior to 2010, all voice dosimeter studies were completed with equipment that sampled the full accelerometer microphone signal once every 20-30ms to extract the presence of phonation (yes or no), $F_{0,}$ and dB SPL at that moment in time. These data were processed to present vocal dosage measurements (voicing percentage, cycle dose, and distance dose) and descriptive statistics on these measurements. Measurements of voice quality were not included. Possibly due to the limited amount of data available, the high expense of the commercially produced devices, and the lack of “statistically robust” studies to evaluate the potential of these devices, the use of this technological advance has been limited to date (Zanartu, 2010).

One creative development has been an attempt to use dosimeters, along with Voice Range Profiles (VRPs), to quantify the tessitura and load of vocal repertoire (Nix, 2014). By quantifying the load characteristics of a musical selection and the VRP of a singer, vocal pedagogues could select repertoire that is an ideal physiological fit for a particular singers’ voice.

Recently, other new methods for accelerometer-based ambulatory phonation dosimetry have been developed that utilize the full accelerometer signal for bio-acoustic measurements (Zanartu, 2010). Mehta, et al. (2012, 2013) proposed the use of a smartphone platform to record a full signal from an accelerometer placed in the sternal notch on the neck. The authors conducted a pilot study (Mehta, Zanartu et al., 2012) on three vocally normal and three dysphonic individuals and found the method to have strong potential, both because of the greatly reduced cost and the ability to investigate additional voice measures through the use of the full, unprocessed accelerometer signal. The pilot study advocated for a method initially proposed by

Cheyne (2002, 2006) to use the accelerometer data to provide an estimate of glottal airflow, thus giving an estimate of vocal efficiency in addition to the traditionally measured vocal dose data. At this date, a full-scale study with data collected on more than 400 participants was underway using this method (Hillman et al., 2013). Ghassemi et al. (2014) found that bioacoustic measurements acquired through ambulatory monitoring with an accelerometer could identify the presence of vocal nodules with considerable accuracy.

Additionally, Sonovox AB in Sweden developed a new dosimeter, the VoxLog, which incorporated both a Knowles BU-1771 Model accelerometer transducer and an audio microphone into a collar worn without adhesive around the neck. The commercially available VoxLog included a portable computer with analysis software built in. Several studies have been completed to date using the VoxLog, all of which focus on vocal dose and the relationship between phonation activity and ambient sound, i.e., the Lombard effect, some with additional analyses of biofeedback techniques and perceived voice function (Graca & Öhlin, 2013; Lindstrom, Waye, Södersten, McAllister, & Ternström, 2011; Nygren, Tyboni, Lindström, McAllister, & van Doorn, 2012; Petersson & Järåsen, 2012; Schalling, Gustaffsen, Ternström, Wilén, & Södersten, 2013; Skoglund & Fhärm, 2013; Södersten, Thorsdotter, McAllister, & Terström, 2011). Hunter (2013) proposed use of the VoxLog's collar with an off-the-shelf digital recorder and open-source software as an effective and affordable method for conducting voice dosimetry.

Summary

A considerable number of studies have analyzed the vocal dose acquired by various populations. Still other studies have explored the impact of vocal loading on voice quality or the self-perception of vocal fatigue. Yet due to the limitations of previously available technology, few studies have analyzed voice quality and vocal dose for the same voicing periods in a natural setting.

In light of currently available technology, few studies have compared accelerometer acquired bioacoustic spectral measurements with simultaneously acquired vocal dose measurements, and no studies have compared vocal dose with accelerometer acquired voice clarity and perturbation measures such as pitch strength, HNR, shimmer and jitter. Further, no studies have directly compared voice quality measurements simultaneously recorded by an accelerometer and an audio transducer.

The VoxLog collar combined with a standard digital recorder seemed an excellent choice for simultaneous ambulatory monitoring of vocal dose and voice quality. The collar, as reconfigured, was convenient to use in that it did not require adhesive and, in this study, was connected to a recorder hidden under the participants' clothes. It recorded an unfiltered accelerometer signal, which was analyzed for voice quality measures without undue influence of ambient sound, and it recorded ambient sounds in a separate acoustic microphone for comparison.

With these capabilities in mind, a study was undertaken that utilized both VoxLog transducers. The accelerometer was utilized for extended ambulatory monitoring, simultaneously collecting dose measures (phonation percentage, Dt, Dc, and Dd) and voice quality measures (F_0, P_0, dB SPL, LTAS slope, alpha ratio, dB SPL 1-3 kHz, pitch strength, shimmer, jitter, and harmonic–to-noise ratio). The audio microphone was utilized to collect data from a series of vocal tasks that were completed by the participants in a quiet environment at certain points during each day of ambulatory monitoring. These tasks provided data on the above ten voice quality measures during repetitions of the same tasks so that changes during monitoring could more accurately be assessed. The vocal tasks also offered comparisons that allowed further testing on the reliability of bio-acoustic voice quality data acquired from the accelerometer. As open-source software was being explored as a method to keep the cost of dosimetry affordable, two open-source algorithms, PRAAT and Audswipe, were employed for the extraction of many of these data both due to their open-source availability and accuracy.

CHAPTER 3

Methodology

The purpose of this study was to assess the voice use, voice quality, and perceived singing voice function of college/university singing students (*N* = 19), ages 18-24 years, enrolled in both voice lessons and choir at a small liberal arts college, through (a) measurements of vocal dose and voice quality, collected over three full days of ambulatory monitoring and disaggregated by activity, with an unfiltered neck accelerometer signal acquired with the Sonovox AB VoxLog portable voice analyzer collar; (b) measurements of voice quality during singing and speaking vocal tasks acquired at three different times of day acquired by both the contact accelerometer and the acoustic microphone included in the VoxLog collar; and (c) multiple applications of the Evaluation of the Ability to Sing Easily (EASE) questionnaire about perceived singing voice function. This chapter details the participants, methods, and procedures employed to accomplish this purpose.

Participants

A convenience sample of 25 college/university students began the study. None of these students reported a history of any vocal pathology. The students represented four different institutions of higher education (a private two-year college, a private four-year college, and two masters level state universities) and five different private voice teachers.

Of these initial participants, two students withdrew from the study. Twenty-three students completed three days of monitoring, but four of them had large gaps in recording, necessitating their removal from the study. Nineteen students successfully completed three days of at least 10.5 hours of monitoring per day. Therefore, I used data from only these 19 participants (11 men, 8 women) in full day data analyses. For this study, I considered 10.5 hours or more as a “full” day. This research decision conformed to accepted practice in other ambulatory monitoring studies with uneven compliance (e.g., Ghassemi, et al., 2014).

The 19 participants recorded for an average of 14 hours 36 minutes each day. They had the monitor turned off for an average of 31 minutes of reported waking hours, with a range of zero minutes to 4 hours 23 minutes not recorded. Students turned the monitor off for participation in contact sports, avoiding contact with water (showering or swimming), private conversations (acceptable per the study consent form), and encountered equipment difficulties.

Table 1 provides basic demographic data for these 19 participants. Three two-tailed independent samples *t*-tests, *t*(18), revealed no significant differences between age, years of choral experience, or years of voice lessons between these men and women.

Table 1

*Demographic Data: Participants (*N *= 19) Completing Three Full Days of Monitoring*

	Mean	Mode	SD	Range	*M* Men	*M* Women	*t*-test for Sex *t*	*p*
Age	19.95	19	2.51	6	20.00	19.89	.132	0.896
Years in Choir	8.40	7	3.7	13	7.27	9.78	-1.483	0.163
Years of Voice Lessons	2.78	0.5	2.55	7.5	2.86	2.67	.168	0.864

In addition to daily ambulatory voice monitoring, I asked all study participants to complete a set of four vocal tasks three times daily (morning, afternoon, evening) at specified times. However, six of 19 participants either failed to complete all the tasks or completed some of these vocal tasks within fewer than four hours of one another. Therefore, I used data from 13 participants (7 men, 6 women) for vocal tasks analyses. Table 2 provides basic demographic data for the 13 participants for whom the sets of vocal tasks were analyzed. Three two-tailed independent samples *t*-tests, *t*(11), revealed no significant differences between age, years of choral experience, or years of voice lessons between men and women among this group of participants.

Table 2

*Demographic Data: Participants (*N *= 13) Completing All Vocal Tasks and Three Full Days*

	Mean	Mode	SD	Range	*M* Men	*M* Women	*t*-test for Sex *t*	*p*
Age	20.10	20	1.50	6	20.43	19.83	.716	.489
Years in Choir	8.30	7	3.68	13	7.00	9.83	-1.385	.194
Years of Voice Lessons	2.42	0.5	1.85	5.5	2.21	3.17	-.782	.451

Initial Meeting

All participants completed an Institutional Review Board consent form (Appendix B) and a short demographic questionnaire (Appendix B) during their first meeting with the researcher. The questionnaire asked participants to identify their sex, age, number of semesters enrolled in college/university, estimated hours of singing per week during the current semester, years of voice lesson experience, years of choral experience, and whether they had ever dealt with a vocal injury or worked with a Speech Language Pathologist to resolve a voice-related issue. The questionnaire also asked students to confirm their current participation in a college choir and voice lessons and their current vocal health. I eliminated from the study any potential participant not enrolled in choir or voice lessons, or who reported a current unresolved vocal pathology.

Finally, I asked participants if they could sing the first verse of the tune “Amazing Grace” (henceforth Amazing Grace). Because I used this song for vocal tasks throughout the study, at this first meeting I taught the song and provided a score to students who initially responded they did not know the song.

Ambulatory Monitoring

All participants (*N* = 19) wore one of two VoxLog portable voice analyzer collars all waking hours during three weekdays while classes were in session. They also wore the collar for one short period in the voice studio the day prior to their first day of monitoring, during which time they completed brief singing and speaking tasks in order to determine a baseline for voice quality.

The VoxLog collars were placed around the participant’s neck, adjusted to comfortably fit the circumference of the neck, and attached to a standard digital recorder (Figure 3). At the end of each collar were two transducers: one transducer was a Panasonic WM-61A omnidirectional microphone ("Panasonic Omnidirectional Back Electret Condenser Microphone Cartridge," 2103) to sample the airborne acoustics, and the other was a Knowles BU-1771 Model accelerometer ("BU Series Accelerometers," 2013). At the end of the connection was a standard stereo 1/8th in headphone jack. The jack plugged in to a Roland R-05 digital sound recorder (with storage to a 16 GB SD card) that captured the transducer data in a .wav file and provided the power needed to run the VoxLog collar (Figure 4). Participants carried the Roland R-05 in a Tune Belt Vertical Microphone Transmitter Carrier Belt worn around the participant’s midsection underneath the clothes (Figure 2).

Figure 2. Tune Belt Vertical Microphone Transmitter Carrier Belt.

Figure 3. VoxLog collar worn around the neck and attached to digital recorder.

Figure 4. Roland R-05 Digital Recorder.

Data were obtained over the entire course of each of the three full monitoring weekdays. The participants wore the monitors 10.5-18.0 hours each day, putting the monitors on immediately after dressing in the morning and removing the monitors just before retiring for the evening. Standard AA batteries, shown to be sufficient for a 20+ hour day in testing, were used to provide power. On the second and third morning of monitoring, each participant replaced the batteries and inserted a blank 16GB SD card (externally labeled Day 1, Day 2, Day 3) in the recorder. Approximately 2 GB of data were recorded for each 3.33 hours of monitoring. I remained available by phone throughout the study periods in the event that the VoxLog collars or digital recorders had any technical problems. I transferred the captured unprocessed data to a separate external hard drive and backed them up on a cloud storage system at the end of each participant monitoring period.

Vocal Tasks

In order to assess voice quality at different times of day, 13 participants recorded brief singing and speaking tasks with the VoxLog collar three times daily and during an initial meeting with the researcher to attain a baseline reading. The vocal tasks were:

1. The participant sang a sustained /a/ vowel at a comfortable pitch.
2. The participant spoke a sustained /a/ vowel at a comfortable pitch.
3. The participant sang one verse of the song Amazing Grace in a comfortable range a cappella.
4. The participant spoke the first six lines of the “Rainbow Passage” (henceforth Rainbow Passage), a standard passage used to evaluate an individual’s ability to produce healthy connected speech (Fairbanks, 1969):

> When the sunlight strikes raindrops in the air, they act like a prism and form a rainbow. The rainbow is a division of white light into many beautiful colors. These take the shape of a long round arch, with its path high above, and its two ends apparently beyond the horizon. There is, according to legend, a boiling pot of gold at one end. People look but no one ever finds it. When a man looks for something beyond his reach, his friends say he is looking for the pot of gold at the end of the rainbow. (p. 124-139)

Verbal and written instructions (Appendix B) were provided regarding the timing of morning, afternoon and evening task repetitions during each monitoring day. Given students’ schedules and dormitory noise concerns, I instructed participants to complete the morning tasks as early as possible and the evening tasks as late as possible before retiring, and to complete each task at least two hours after eating. It became apparent that the guidelines provided were too strict for college students who often had widely varying schedules from day to day, sometimes not beginning their "morning" until nearly noon and staying awake until nearly 3 a.m. I decided to analyze vocal tasks data for those participants who completed the tasks with a period of at least four hours between each task set. The mean morning task completion time was 9:28 a.m. (*SD* = 1 hr 16 min), the mean afternoon completion time was 4:15 p.m. (*SD* = 1 hr 29 min), and the mean evening completion time was 11:00 p.m. (*SD* = 3 hr 51 min).

Activity Logs

In order to determine what activities occurred during each recorded phonation period and when, the participants completed daily activity logs (Appendix D). Each participant documented each vocal task and significant activity throughout the day along with the time each activity commenced and ended by noting the exact time displayed on the Roland digital recorder. I used the logs to disaggregate and calculate voice use during different activities.

Perceived Singing Voice Function Questionnaires

Participants completed the validated Evaluation of the Ability to Sing Easily (EASE) questionnaire, which assessed each participant's perceptions of the current status of his or her singing voice (Appendix E). Participants completed the questionnaire four times: (a) during the first meeting with the researcher one day prior to the first monitoring day and, thereafter, (b) at the end of each of the three days of ambulatory monitoring after they had removed the monitor.

Pilot Studies

VoxLog vs. acoustic head-mounted microphone. In order to determine the reliability of the VoxLog collar transducers and the equipment's ability to complete a full day of monitoring continuously and to test protocols for data analysis, I undertook a small pilot study at the National Center for Voice and Speech. One 42-year-old male participant wore the VoxLog collar over the course of one entire day. During this day of monitoring, he completed several vocal tasks at two different times. During each set of tasks, the VoxLog collar recorded in conjunction with a separate audio recorder and a head mounted microphone. The tasks included repetitions of the hymn Amazing Grace and a short excerpt from an opera aria.

Table 3

Three Transducers – Percentage Agreement During Four Short Singing Tasks Performed by an Operatic Tenor

Measure	VoxLog Audio / Head Mic	VoxLog Acc / Head Mic	VoxLog Acc / VoxLog Audio
Po *Mean*	100.04%	99.75%	99.70%
Po *STD*	99.37%	99.87%	100.51%
Po *Med*	100.07%	99.79%	99.72%
Pitch strength *Mean*	94.56%	102.12%	108.00%
Pitch strength *STD*	106.88%	93.49%	99.91%
Pitch strength *Med*	94.85%	102.90%	108.49%
dB SPL *Mean*	97.36%	96.44%	99.05%
dB SPL *STD*	88.79%	66.58%	74.99%
dB SPL *Med*	96.43%	95.34%	98.87%
dB SPL 1-3 kHz	80.48%	90.57%	112.54%

Note. A percentage above 100% indicates a higher mean for the audio transducer reading listed on top while a percentage below 100% indicates a higher mean for the transducer listed on the bottom

I compared the data from the head-mounted audio recorder, the VoxLog audio microphone, and the VoxLog contact accelerometer transducer in terms of $P_{0,}$ dB SPL and pitch strength (mean, median, and standard deviation) and dB SPL 1-3 kHz using a script in MATLAB[1]. The three transducers showed strong agreement on most of these measures, with

[1] Hunter authored all MATLAB scripts used in this investigation.

better than 99% agreement on all P_0 measurements. The spectral measurement of dB SPL 1-3 kHz showed less agreement between the three transducers

VoxLog vs. KayPentax Ambulatory Phonation Monitor. In a second pilot study, two individuals, an adult male and an adult female, wore the VoxLog collar in conjunction with a KayPentax Ambulatory Phonation Monitor (APM) owned by the University of Kansas Vocology Lab for approximately 14 hours each. The male was a college voice teacher and the monitoring hours included several hours of teaching voice lessons at the piano. The female was a violin teacher and her hours included several hours of violin teaching and a session of choral singing.

I compared acquired accelerometer data from the two devices in terms of Mean F_0, Mean P_0 (VoxLog only), Dt, voicing % and cycle dose. Due to problems with the calibration of the KayPentax APM, I did not compare dB SPL and Dd readings. For each device, I selected identical upper and lower F_0 thresholds. Due to the difference in calibrations, I selected individualized lower dB SPL thresholds for each individual and each device, based on direct observed comparison to the recorded VoxLog Audio files. I analyzed the VoxLog data using a MATLAB script. Two different algorithms were explored for F_0 extraction, PRAAT and Audswipe. The PRAAT results were reported as F_0 and the Audswipe results were reported as P_0. The VoxLog vocal dose measurements were calculated by taking the average measurement outputted by the two algorithms.

The full day comparisons for each individual appear in Table 4. Due to the larger differences between the device readings of the woman's full day, her recording was disaggregated by activity between non-music periods, teaching violin, and choral singing (Table 5). This comparison revealed relatively close agreement between the devices during the non-music period but a larger difference during choral singing and a still larger difference during violin teaching. Direct comparisons of one-minute windows to audio data confirmed that both devices interpreted some violin playing as voicing.

Table 4

Vox Log vs. KayPentax APM Full Day Comparisons

	Male			Female		
	VoxLog	APM	*P* Agreement	VoxLog	APM	*P* Agreement
Minutes Monitoring	833	833		838	839	86.0
Time Dose (minutes)	133.75	132.17	98.83	171.35	147.40	88.7
Voicing %	16.05	15.87	98.83	19.82	17.58	80.1
Cycle Dose (kilocycles)	1287.04	1211.07	94.1	3064.14	2384.92	88.5
F_0 *Mean*	160	155	96.80	304	269	84.0
P_0 *Mean*	169		91.65	310		86.0

Note. *P* indicates the percentage of agreement between the two devices. A *P* below 100% indicates a higher mean for the VoxLog accelerometer readings. A *P* above 100% indicates a higher mean for the APM readings. *P* agreement for P_0 shows the agreement between the VoxLog P_0 and the APM F_0.

Table 5

Female Violin Teacher Data Disaggregated By Activity

	Non-Music			Violin Teaching			Choral Singing		
	VoxLog	APM	*P* Agree-ment	VoxLog	APM	*P* Agree-ment	VoxLog	APM	*P* Agree-ment
Minutes Monitoring	493	494		279	279		66	66	
Time Dose (minutes)	58.01	58.18	100.3	92.20	68.05	81.3	24.43	21.27	87.1
Voicing %	11.77	11.78	100.1	30.00	24.39	81.3	37.01	32.23	87.1
Cycle Dose (kilocycles)	885.1	842.6	95.2	1561.1	965.9	61.9	617.7	576.3	104.8
F_0 *Mean*	263	241	91.7	306	236	77.3	414	452	109.1
P_0 *Mean*	210		114.8	321		73.7	431		106.5

Note. *P* indicates the percentage of agreement between the two devices. A *P* below 100% indicates a higher mean for the VoxLog accelerometer readings. A *P* above 100% indicates a higher mean for the APM readings. *P* agreement for P_0 shows the agreement between the VoxLog P_0 and the APM F_0.

Data Collection and Processing

Audio processing. The Roland R-05 recorded all collected VoxLog data in .wav files, with the left channel recording accelerometer data and the right channel recording acoustic transducer data. I processed these files using GoldWave v5.70 digital audio editing software (GoldWave, 2013). Editing included separating the VoxLog audio and accelerometer signal data into unique data files as well as extracting data files for different activity periods and vocal tasks for comparison. I reduced the sampling rate for each file from 44100 kHz to 14700 kHz in order to in order to make file sizes manageable. This sampling rate was lower than that recommended by Deliyski, Shaw, and Evans (2005) and Titze (1994) because the accelerometer signal had a more limited frequency range and because high frequency analysis would have required a controlled, quiet environment, but it still contained enough detail to complete robust data analyses. The accelerometer files recorded signals at a much lower intensity level than the audio files, so I completed normalization of these files by increasing the volume of the files by 25-30 dB SPL, the maximum level that could be reached without clipping voicing data.

Calibration. Each participant completed an SPL calibration using a process involving an SPL reading with a Mini Digital Sound Level Meter DT-85A. During the first meeting between the researcher and the participant in a quiet room, the participant completed a series of three spoken /a/ vowels at a comfortable pitch while holding a standard sound level meter at a distance of 30cm from the mouth (Figure 5). The VoxLog collar was affixed and recording simultaneously with an iPad video recorder when the /a/ vowels were completed. I processed the

/a/ vowel files in Goldwave as described above.

Figure 5. SPL calibration at 30cm.

I observed the video of each /a/ vowel frame by frame and recorded each dB SPL level on a spreadsheet, with each /a/ vowel containing between 8 and 32 data points. I dropped the first two and final data points of each /a/ vowel in order to obtain the most accurate readings of the sustained phonation and obtained an average dB SPL reading for each /a/ vowel.

I then employed a calibration script created for MATLAB to obtain calibration levels for each participant and each transducer. The script prompted the researcher to select sound segments from the Baseline tasks .wav file. I entered the corresponding SPL levels obtained from the sound level meter and MATLAB calculated both an offset dB SPL level (to be added to the base dB SPL level of a reading after processing was completed at a standard relative dB level in MATLAB) and a gain level (to replace the standard relative gain level in the MATLAB script and produce a calibrated SPL reading upon output) (Figure 6). I repeated this process to provide calibrations for both the accelerometer and the audio transducers. In two cases, the MATLAB script was unable to properly segment /a/ vowels for calibration from the accelerometer file when amplified by 30 dB SPL. In these instances, I employed a further amplification of 10-20 dB to obtain the calibration and that same 10-20 dB offset was then added to the accelerometer output.

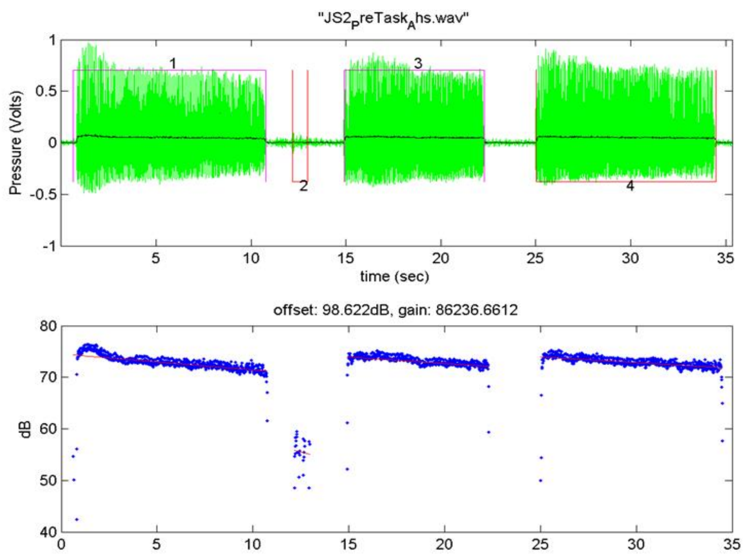

Figure 6. Participant accelerometer calibration output from MATLAB.

Vocal tasks data processing. I batch processed the short vocal tasks in groups of 10 by participant, transducer, and task type in MATLAB scripts. I processed the tasks using the appropriate calibrated gain level and with an F_0 bandwidth of 70-600 Hz. I used separate scripts for /a/ vowels and for the two longer speaking/singing tasks. Variables included F_0, P_0, dB SPL, LTAS slope, alpha ratio, dB SPL 1-3 kHz, pitch strength and duration of the task. The two /a/ vowel tasks only also included shimmer, jitter, and HNR. The MATLAB script employed PRAAT software to obtain F_0, shimmer, jitter, and HNR. It also employed the Audswipe' algorithm to obtain P_0 for comparison with the F_0 readings. The output for F_0, P_0, pitch strength, dB SPL included the mean, median, interquartile range (IRQ), variance, standard deviation, skewness, and kurtosis. The MATLAB script produced an output of all the requested variables in individual file reports (Figure 7) and a summary text file formatted for Microsoft Excel spreadsheets. I then cut and pasted these raw data into Excel file templates for analysis.

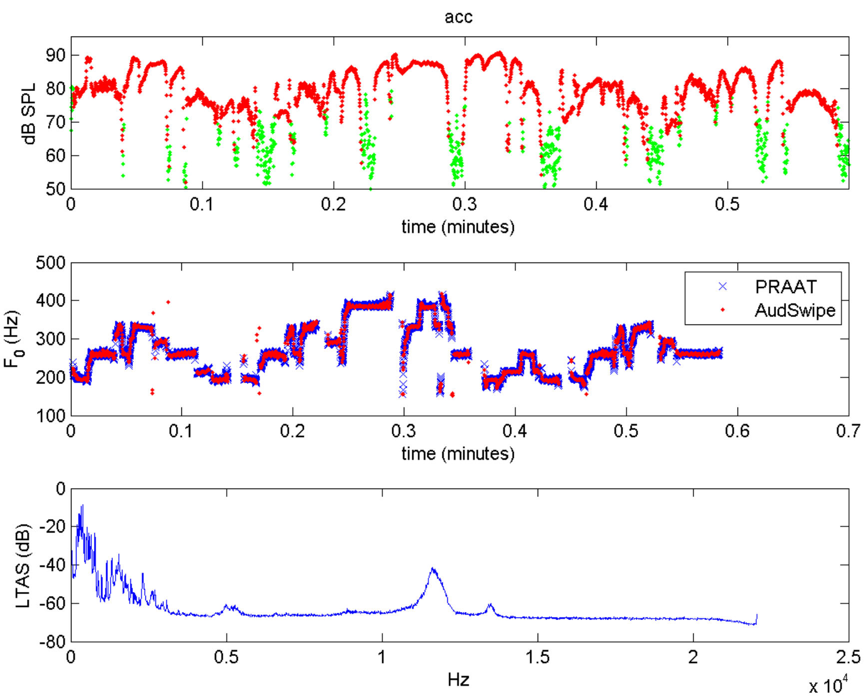

Figure 7. Summary report for a vocal task repetition of Amazing Grace.

Long-term data processing. I processed long-term monitoring .wav file data in MATLAB. MATLAB loaded the .wav files in 1 minute increments. The script employed PRAAT software and the Audswipe' algorithm to estimate F_0/P_0 and dB at 10ms intervals. Then the script concatenated collected VoxLog data and completed additional analysis on the concatenated voicing components within each 1 min window. Output included voicing percentage, LTAS slope, alpha ratio, dB SPL 1-3 kHz, shimmer, jitter, and HNR as well as the mean, median, IRQ, standard deviation, skewness, and kurtosis of Fo, P_0, pitch strength, and dB SPL. The script completed voice quality analyses only on the voiced segments as judged by the PRAAT algorithm. The MATLAB script repeated this process for each minute of the full day files and saved an output file with aggregated data for each minute. I used an Excel spreadsheet template to aggregate the time interval data and calculate the results of each measure for the entire period analyzed, with appropriately weighted averages. The Excel spreadsheet also employed formulas that compiled Dc, Dt, and Dd. The MATLAB script produced several output figures for each long-term period analyzed (Figure 8 and Figure 9).

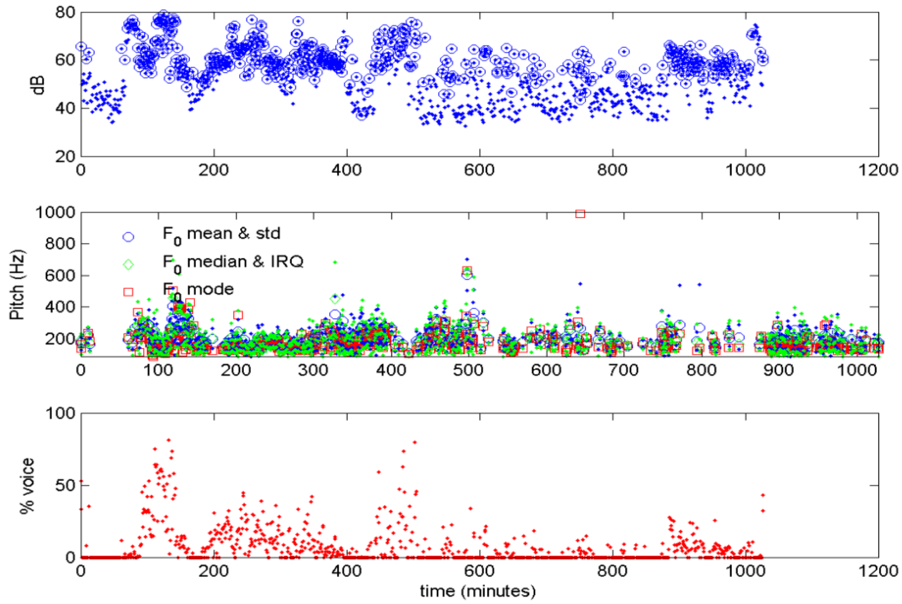

Figure 8. Full day analysis output file from MATLAB.

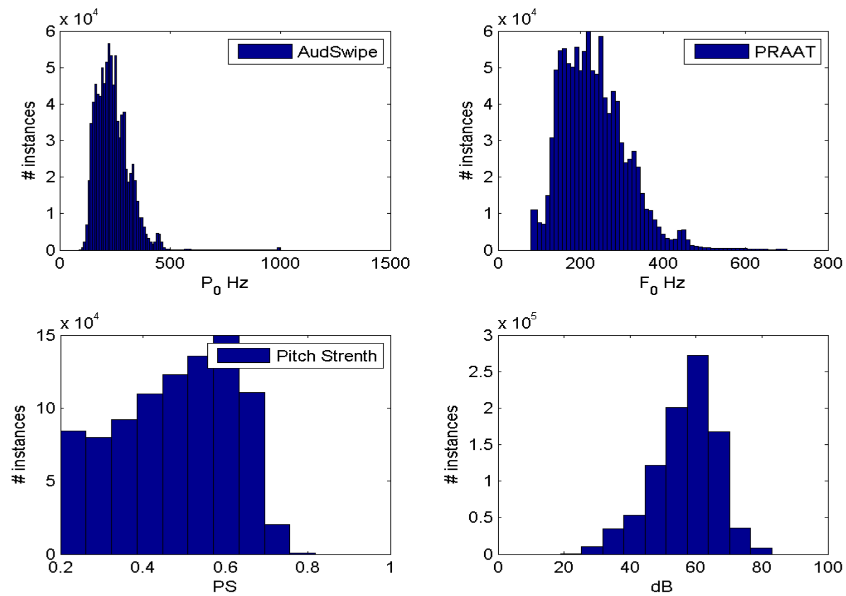

Figure 9. Histograms of full day analysis of F_0, P_0, PS and dB SPL.

Analysis parameters and assumptions.

Based on the literature (e.g., Camacho, 2010; Ghassemi et al., 2013; Hillman et al., 2013; Hunter, 2013; Mehta, Zanartu et al., 2013; Zanartu, 2010) and testing of the above method, I employed the following protocols in analysis:

Determination of voicing, F_0, P_0. The algorithms determining F_0 (PRAAT) and P_0 (Audswipe) also determined the presence of voicing, voicing percentage, Dt, Dc and Dd. MATLAB used a selection process to determine the presence of voicing. If voicing was identified by PRAAT but that segment was not longer than 40 msec, it was not deemed voicing and was discarded. If a full minute of analysis contained less than 180 instances of voicing out of a possible 6000 instances (less than 3 percent), any readings of voicing during the full minute were also discarded. Due to the possible presence of lower levels of ambient periodic sound in the recordings, MATLAB discarded readings of voicing if the calibrated SPL level was below 47 dB SPL.

MATLAB's output of PRAAT's F_0 and Audswipe's P_0 demonstrated differences between the two algorithms. At levels of higher than 60 dB SPL, a Pearson correlation coefficient test showed a stronger relationship between the two algorithms among all one minute ouputs, $r(22844) = .923$, than at levels between 47 dB SPL and 60 dB SPL, $r(3205) = .803$. In observation, it was noted that at these lower dB levels, one or both algorithms sometimes misinterpreted captured ambient periodic sound as voicing, and those ambient sounds were usually recorded at a lower dB SPL level than voiced sounds. The ambient periodic sound was reduced as much as possible by setting a new lower dB SPL level threshold (above the initial 47 dB SPL threshold outputted by the MATLAB script) that was individualized to each participant and running a secondary MATLAB script to filter out any data readings below that threshold. It was necessary to create individualized thresholds because of varying levels of difference between the highest recorded levels of ambient sound and the lower dB SPL threshold of voicing for each individual. Therefore, for each individual, I observed at least five and up to fifteen minutes of recording with very low dB SPL readings (as compared to the rest of the output) using Goldwave audio software. After listening, a final dB SPL threshold for that participant was set at the level of the whole integer below the lowest level of observed voicing, and all readings for any minutes with a dB level under the threshold were converted entirely to zero.

In observational comparisons with audio files, neither PRAAT nor Audswipe demonstrated clear superiority in voicing analysis over a full day. Therefore, I decided to employ and report the findings for both algorithms. F_0 and P_0 results were reported and compared separately. For the full day files and corresponding activities, I used the average of the two readings to determine Dt, Dc, Dd and dB SPL.

Analyzing long-term average spectrum, alpha ratio and dB SPL 1-3 kHz. LTAS was calculated per an analysis partially described in Monson, Hunter, and Story (2012). LTAS was calculated using only parts of the signal that tested positive for the presence of voicing, with 31 overlapping frames in time. A Hamming window was used with windows of 0.7430 seconds. Each of the 31 windows overlapped with the previous one in time. Then an average of the spectra for each window was calculated (only voicing windows). The spectrum employed was a 1.3458 Hz resolution.

Once the LTAS was obtained, MATLAB applied a direct linear line fit to the spectrum between the median F_0 and 5000 Hz to obtain the LTAS slope in dB/Hz. The alpha ratio for any designated period of time was determined by taking the LTAS for the period and dividing the total intensity in dB from 1001-5000 Hz by the total intensity from 50-1000 Hz. The total intensity of the sound between 1 kHz and 3 kHz (3,125 Hz) was also measured as another means of determining spectral intensity of the voice (Krause & Braida, 2004).

Disaggregation by activity. I analyzed data from each of the three full monitoring days as a whole and as disaggregated by activity. Disaggregations included choral singing, solo singing, instrumental playing and non-singing time. Due to consistent problems with the MATLAB script interpreting instruments in close proximity as voicing, all instrumental playing minutes were removed from the overall analysis. If solo singing was part of a musical or opera staging rehearsal, I disaggregated the rehearsal minutes into active singing minutes (solo singing) and non-signing minutes. I took other activities, such as voice lessons or choral rehearsal, as a whole. I compiled vocal dose and voice quality measurements for each segmented activity in one-minute intervals (using the MATLAB output) and then aggregated those data to determine overall activity measurements for each individual and the study population.

Ambulatory data correlation test parameters. I ran correlation tests between each of the four measures of vocal dose (Voicing %, Dt, Dc, and Dd) and most of the ten measures of voice quality (F_0, $P_{0,}$ dB SPL, LTAS slope, alpha ratio, dB SPL 1-3 kHz, pitch strength, shimmer, jitter, and harmonic-to-noise ratio). Some of the vocal dose measures were derived in part from one or more of the voice quality measures: (a) F_0 and P_0 were a factor in Dc (a higher frequency equaled a more vibratory cycles) and (b) Db SPL and $F_{0/}P_0$ were part of the formula used to calculate Dd. Because of these factors, a strong positive correlation between these variables was a given and not meaningful to the study results. I did not run correlation tests between Dc and F_0 or P_0, nor did I run correlation tests between Dd, and dB SPL, $F_{0,}$ or $P_{0.}$

EASE scores. I totaled the EASE questionnaire's overall and subset scores and analyzed for statistically significant changes between the three administrations of the survey. I employed

Pearson correlation coefficient tests to see if there would be statistically significant relationships between the EASE overall and subset scores and cycle dose, distance dose, and the mean scores of the above acoustical measures.

CHAPTER 4

Results

Results are presented according to the research questions posed for this investigation. A pre-determined alpha level of .01 served to indicate significance for all statistical tests. I chose this alpha level in lieu of an alpha level of .05 with applied Bonferroni corrections, a method that I considered too conservative when considering the large number of within-family tests.

Research Question 1: Relationships of Vocal Dose and Voice Quality During Full Days of Ambulatory Monitoring

I looked for statistically significant relationships between each of four measures of student vocal dose (phonation percentage, dose time, cycle dose, and distance dose) and each of ten measures of voice quality (F_0, P_0, dB SPL, LTAS slope, alpha ratio, dB SPL 1-3 kHz, pitch strength, shimmer, jitter, and harmonic-to-noise ratio) acquired with the VoxLog collar's unfiltered accelerometer signal a) over three full days of ambulatory monitoring and b) between three types of activities (non-singing, choral singing, and solo singing).

Full days and activities totals. I collected accelerometer data for all the above variables over three full ambulatory monitoring days and disaggregated the full days into different activities: choir, solo singing, non-singing (N = 19). Totals and measures of central tendency per day and for each activity are displayed below for all participants (Table 6), men (Table 7) and women (Table 8).

Table 6

*Measures of Central Tendency, Full Monitoring Days: All Participants (*N *= 19)*

Measure	Total	Non-Sing	Choral*	Solo
Rec. Hrs. – Total	42.69	37.80	2.93	2.16
Voicing %	11.92	8.63	38.10	34.50
Dt –Total (min)	305.25	195.65	62.65	44.79
Dt - Per Hour (min)	7.15	5.18	22.86	20.70
Dc – Total (Kc)	4153.53	2483.88	919.24	761.66
Dc - Per Hour (Kc)	97.32	65.71	334.40	351.96
Dd - Total (m)	15815.04	9248.14	3783.41	2879.60
Dd - Per Hour (m)	370.57	244.65	1376.31	1330.66
F_0 Mean (Hz)	228.04	214.77	238.57	283.04
F_0 Median (Hz)	215.13	199.04	230.35	275.84
F_0 Mode (Hz)	192.88	178.75	206.07	239.64
F_0 St Dev (Hz)	73.21	71.86	74.01	83.96
P_0 Mean (Hz)	225.41	205.36	249.47	285.36
P_0 Median (Hz)	216.22	193.93	245.06	278.85
P_0 Mode (Hz)	210.60	189.85	233.41	269.01
P_0 St Dev (Hz)	63.36	57.99	70.38	81.55
dB SPL Mean	76.95	75.18	78.47	79.16
dB SPL Median	77.20	75.67	79.42	78.82
dB SPL Mode	77.47	75.66	80.22	79.59
dB SPL St Dev	5.47	5.30	5.66	6.08
LTAS Slope (x100)	-0.58	-0.55	-0.63	-0.01
Alpha ratio	-23.15	-22.66	-23.95	-24.08
dB SPL 1-3 kHz	-56.87	-56.51	-57.98	-56.72
Pitch Strength *M*	32.27	29.80	35.95	38.69
Pitch Strength *SD*	10.81	10.77	10.47	12.23
Jitter	0.032	0.037	0.025	0.025
Shimmer	0.128	0.139	0.123	0.10
HNR	11.86	10.61	13.65	15.34

Note. Only 15 of the 19 participants participated in a choral rehearsal during the study period. The choral singing results represent the averages for only these 15 participants.

Table 7

*Measures of Central Tendency, Full Monitoring Days: Men (*N *= 11)*

Measure	Total	Non-Sing	Choral*	Solo
Rec. Hrs. – Total	42.54	37.35	3.66	1.98
Voicing %	13.07	9.28	38.30	36.89
Dt –Total (min)	335.55	208.06	84.01	43.86
Dt -Per Hour (min)	7.84	5.57	22.98	22.13
Dc – Total (Kc)	3475.61	2004.77	1006.50	520.17
Dc - Per Hour (Kc)	81.25	53.67	275.33	262.47
Dd - Total (m)	17914.26	10049.29	5068.46	3094.60
Dd - Per Hour (m)	418.76	269.05	1386.51	1561.49
F_0 Mean (Hz)	171.56	158.97	196.42	195.22
F_0 Median (Hz)	162.81	147.75	191.90	191.04
F_0 Mode (Hz)	148.47	133.68	176.26	175.49
F_0 St Dev (Hz)	53.42	52.83	55.55	55.13
P_0 Mean (Hz)	174.19	159.26	202.60	200.00
P_0 Median (Hz)	166.53	149.83	197.45	195.47
P_0 Mode (Hz)	164.37	148.89	195.55	188.29
P_0 St Dev (Hz)	48.90	46.55	51.55	56.36
dB SPL Mean	78.14	76.14	78.74	82.65
dB SPL Median	78.50	77.09	79.49	83.68
dB SPL Mode	78.86	77.18	80.26	84.67
dB SPL St Dev	5.50	5.29	5.53	6.63
LTAS Slope (x100)	-0.61	-0.58	-0.64	-0.69
Alpha ratio	-23.76	-23.32	-24.62	-24.15
dB SPL 1-3 kHz	-58.17	-58.11	-58.82	-57.29
Pitch Strength *M*	33.64	30.33	38.11	41.89
Pitch Strength *SD*	11.05	10.80	10.70	12.88
Jitter	0.032	0.038	0.023	0.022
Shimmer	0.123	0.136	0.109	0.092
HNR	12.11	10.62	14.60	15.82

Note. Only 9 of the 11 male participants participated in a choral rehearsal during the study period. The choral singing results represent the averages for only these 9 participants.

Table 8

*Measures of Central Tendency, Full Monitoring Day: Women (*N *= 8)*

Measure	Total	Non-Sing	Choral*	Solo
Rec. Hrs. – Total	42.78	38.42	1.85	2.41
Voicing %	10.33	7.75	37.50	31.80
Dt –Total (min)	263.55	178.60	41.57	46.07
Dt -Per Hour (min)	6.20	4.65	22.50	19.08
Dc – Total (Kc)	5085.72	3142.67	941.57	1093.72
Dc - Per Hour (Kc)	119.55	81.80	509.72	452.96
Dd - Total (m)	12928.60	8146.57	2486.39	2583.98
Dd - Per Hour (m)	303.92	212.04	1346.02	1070.16
F_0 Mean (Hz)	321.40	301.38	355.25	392.52
F_0 Median (Hz)	301.75	278.64	336.82	381.54
F_0 Mode (Hz)	267.16	248.70	288.60	319.60
F_0 St Dev (Hz)	105.14	101.41	125.12	119.90
P_0 Mean (Hz)	320.00	283.50	404.65	402.75
P_0 Median (Hz)	308.00	268.56	402.82	394.46
P_0 Mode (Hz)	295.98	258.32	354.07	380.84
P_0 St Dev (Hz)	90.06	77.26	133.99	116.13
dB SPL Mean	74.74	73.65	74.45	74.60
dB SPL Median	74.81	74.06	79.99	75.17
dB SPL Mode	74.91	73.90	80.74	75.70
dB St Dev	5.41	5.29	5.52	5.75
LTAS Slope (x100)	-0.54	-0.51	-0.59	-0.59
Alpha ratio	-22.09	-21.63	-22.08	-23.99
dB SPL 1-3 kHz	-54.54	-54.03	-55.62	-56.02
Pitch Strength *M*	30.20	28.58	27.80	34.41
Pitch Strength *SD*	10.58	10.54	9.40	11.285
Jitter	0.032	0.036	0.033	0.028
Shimmer	0.135	0.143	0.162	0.11
HNR	11.52	10.60	11.03	14.73

Note. Only 6 of the 8 female participants participated in a choral rehearsal during the study period. The choral singing results represent the averages for only these 6 participants.

Correlations between vocal dose and voice quality over full monitoring days.

I employed Pearson correlation coefficient tests between each of the ten voice quality measures (F_0, P_0, dB SPL, LTAS slope, alpha ratio, dB SPL 1-3 kHz, pitch strength, shimmer, jitter and HNR) and each of the four vocal dose measures not derived in part from a voice quality measure (voicing %, Dt, Dc, and Dd) for two different disaggregations of full-day ambulatory monitoring data: (a) three day totals by participant (N = 19), and (b) individual day totals (N = 57).

Voice quality means for three days vs. three-day vocal dose total. Table 9 displays Pearson correlation results for three-day ambulatory monitoring totals for each participant (N = 19). There were multiple significant correlations between dose measures and perturbation measures, particularly pitch strength and shimmer, and moderately strong though not statistically significant correlations between dose measures and jitter and HNR. In each case, a higher vocal dose correlated with less perturbation.

Table 9

Pearson Correlation Coefficient Tests Between Three-Day Vocal Dose Totals and Voice Quality Means

Measure		Voicing %	Dt	Dc	Dd
F_0	*r*	-.373	-.344		
	p	.116	.149		
P_0	*r*	-.341	-.302		
	p	.153	.209		
dB SPL	*r*	.493	.512	.250	
	p	.032	.025	.302	
LTAS slope	*r*	.068	.041	.393	.020
	p	.783	.868	.096	.934
Alpha ratio	*r*	-.148	-.237	-.112	-.359
	p	.546	.328	.647	.131
dB 1-3kHz	*r*	-.233	-.262	.177	-.224
	p	.337	.279	.468	.357
Pitch strength	*r*	**.665**	**.636**	.296	**.675**
	p	.002	.003	.219	.002
Jitter	*r*	-.501	-.484	-.435	-.432
	p	.029	.036	.063	.065
Shimmer	*r*	**-.689**	**-.672**	-.402	**-.656**
	p	.001	.002	.088	.002
HNR	*r*	.558	.543	.463	**.577**
	p	.013	.016	.046	.010

Note. p < .01, 2-tailed, is indicated in boldface.

Daily voice quality means vs. daily vocal dose totals. Table 10 displays Pearson correlation results for individual ambulatory monitoring day totals for all participants (N = 57). Like the three day totals, there were multiple moderate, significant correlations between various dose measures and perturbation measures among individual daily totals, in this case with each of the four perturbation measures (pitch strength, jitter, shimmer and HNR) having at least one significant correlation with a vocal dose measure. Among the individual days, there were also significant correlations between dB SPL and both voicing % and Dt.

Table 10

Pearson Correlation Coefficient Tests Between Daily Vocal Dose Totals and Daily Voice Quality Means

Measure		Voicing %	Dt	Dc	Dd
F_0	*r*	-.251	-.237		
	p	.060	.076		
P_0	*r*	-.205	-.201		
	p	.127	.134		
dB SPL	*r*	**.401**	**.406**	.213	
	p	.002	.002	.112	
LTAS slope	*r*	-.157	-.171	.163	-.225
	p	.242	.203	.226	.093
Alpha ratio	*r*	-.124	-.138	-.065	-.249
	p	.359	.306	.629	.062
dB 1-3 kHz	*r*	-.166	-.229	.115	-.211
	p	.217	.087	.393	.116
Pitch strength	*r*	**.474**	**.477**	.237	**.603**
	p	<.001	<.001	.076	<.001
Jitter	*r*	**-.508**	**-.447**	**-.414**	**-.498**
	p	<.001	<.001	.001	<.001
Shimmer	*r*	**-.457**	**-.423**	-.220	**-.504**
	p	<.001	.001	.101	<.001
HNR	*r*	**.422**	**.383**	**.382**	**.502**
	p	.001	.003	.003	<.001

Note. $p < .01$, two tailed, is indicated in boldface.

Changes between activities. I disaggregated accelerometer data for the three full ambulatory monitoring days by three different types of activities (non-singing, choral singing, and solo singing). I completed one-way repeated measures ANOVAs with independent variables being the three different types of activities and dependent variables being each of the four vocal dose measures and ten voice quality measures discussed above (Table 11). Because four of the nineteen participants had no choral rehearsal during the three days of monitoring (though all four were enrolled and involved in a college choir), the repeated measures ANOVAS were completed with $N = 15$ participants. I completed Mauchly's test of sphericity on each measure with no significant results, indicating that sphericity could be assumed for each measure. The ANOVA revealed that there were significant differences between activities for all measures except the spectral measures of dB SPL 1-3 kHz and alpha ratio.

Post-hoc pairwise comparisons of activities with Least Significant Difference *t*-tests revealed that the majority of the significant differences between these measures occurred between the speaking voice and singing activities (Table 12). Dose measures and F_0/P_0, dB SPL, shimmer, and HNR all had significant differences between non-singing and both singing activities, but no significant differences between the two types of singing. Alpha ratio and pitch strength were significantly higher in non-singing than in solo singing but not significantly different between choral singing and non-singing. There were four significant differences between choral and solo singing, including LTAS slope (significantly steeper in solo singing than in choral singing), pitch strength (significantly stronger in solo singing), and shimmer and jitter (significantly less perturbation in solo singing).

Table 11

Activity Repeated Measures ANOVA Results

Measure	Non-Sing *M (SD)*	Choral *M (SD)*	Solo *M (SD)*	*Df 1*	*Df2*	*F*	*p*
Voicing %	9.35 (2.82)	39.37 (6.76)	44.34 (7.15)	2	28	156.83	**<.001**
Dt (min/hr)	5.28 (1.69)	23.18 (4.00)	25.63 (3.29)	2	28	213.18	**<.001**
Dc (kc/hr)	64.84 (24.21)	364.94 (132.89)	416.62 (166.86)	2	28	61.026	**<.001**
Dd (m/hr)	255.88(131.21)	1320.38(390.82)	1565.60(494.77)	2	28	109.02	**<.001**
F_0	213.54(74.07)	257.82 (91.89)	272.02 (112.72)	2	28	15.04	**<.001**
P_0	206.16(63.92)	278.89 (111.47)	279.18 (114.44)	2	28	21.91	**<.001**
dB SPL	75.09 (5.31)	77.48 (5.37)	78.49 (5.09)	2	28	12.24	**<.001**
LTAS slp (x100)*	-0.55 (0.86)	-0.64 (0.14)	-0.70 (0.14)	1.4	20.2	3.50	**<.001**
Alpha ratio	-22.15 (3.51)	-23.63 (2.91)	-24.42 (4.13)	2	28	4.60	.019
dB SPL 1-3 kHz	-56.07 (3.67)	-57.34 (3.76)	-56.48 (2.67)	2	28	1.69	.202
Pitch strength	29.35 (4.36)	33.76 (8.45)	38.26 (7.03)	2	28	16.68	**<.001**
Jitter %	3.87 (0.64)	2.67 (0.90)	2.47 (0.74)	2	28	17.03	**<.001**
Shimmer %	13.99 (1.97)	13.10 (3.67)	10.51 (2.39)	2	28	11.57	**<.001**
HNR	10.52 (0.47)	13.01 (0.98)	14.99 (0.74)	2	28	13.05	**<.001**

Note. $p < .01$ is indicated in boldface. *For those variables that violated the assumption of sphericity based on Mauchly's test for sphericity ($p < .05$), a Greenhouse-Geisser correction was applied.

Table 12

Significant Differences Between Activity Means

	P		
Measure	Non-Sing / Choral	Non-Sing /Solo	Choral /Solo
Voicing %	**<.001**	**<.001**	.070
Dt (min/hr)	**<.001**	**<.001**	.056
Dc (kc/hr)	**<.001**	**<.001**	.101
Dd (m/hr)	**<.001**	**<.001**	.022
F_0	**<.001**	**<.001**	.286
P_0	**<.001**	**<.001**	.976
dB SPL	**.007**	**<.001**	.144
LTAS slope	**.002**	**<.001**	**<.001**
Alpha ratio	.071	**.002**	.383
dB 1-3kHz	.109	.613	.152
Pitch strength	.019	**<.001**	**.008**
Jitter	**.002**	**.001**	**<.001**
Shimmer	.299	**<.001**	**.010**
HNR	**.004**	**<.001**	.093

Note. *p* < .01 is indicated in boldface.

Correlations between singing time and overall voice quality readings. Overall three day measurements had significant positive correlations in terms of dB SPL, pitch strength and HNR and significant negative correlations in terms of shimmer and jitter. Singing activities had significantly higher dB SPL, pitch strength and HNR and significantly lower shimmer and jitter than non-singing. Because these findings corresponded, I asked if these significant full day correlations could have been influenced by the total amount of singing time and singing dose. I disaggregated singing and non-singing time and ran Pearson correlation tests among the amount of total singing time recorded, three day total singing doses (Dt, Dc and Dd), three day total non-singing doses (Dt, Dc and Dd), and the overall three day totals (singing and non-singing together) for dB SPL, pitch strength, jitter, shimmer and HNR (Table 13). Results revealed moderate to strong correlations between the amount of singing time and each of the five voice quality measures, with significant correlations at the .01 level for dB SPL, pitch strength, shimmer, and jitter. While non-singing time had weak to moderate correlations that moved in the same direction, there were no significant correlations between non-singing Dt or recording duration and these four voice quality measures.

Table 13

Pearson Correlations Between Three Day Voice Quality Means (All Recorded Hours) and Total Singing / Non-singing Doses

Measure		Total Singing Recording Duration	Total Singing Dt	Total Singing Dc	Total Singing Dd	Total Non-Singing Dt	Total Non-Singing Dc	Total Non-Singing Dd
dB SPL	*r*	.395	.496	.401		.395	.126	
	p	.094	.031	.089		.094	.607	
Pitch strength	*r*	.564	**.648**	.498	**.743**	.441	.123	.508
	p	.012	.003	.030	<.001	.059	.615	.026
HNR	*r*	.470	.548	**.590**	**.633**	.403	.311	.440
	p	.042	.015	.008	.004	.087	.195	.059
Jitter	*r*	-.570	**-.667**	**-.637**	**-.628**	-.443	-.378	-.481
	p	.011	.002	.003	.004	.057	.111	.037
Shimmer	*r*	**-.618**	**-.683**	-.509	**-.701**	-.477	-.174	-.456
	p	.005	.001	.026	.001	.039	.477	.050

Note. $p < .01$ is indicated in boldface.

Correlations between non-singing doses and non-singing quality. In order to examine the relationship between non-singing doses and voice quality during non-singing periods more closely, I ran Pearson correlation tests between three day non-singing vocal doses and five voice quality measures acquired during only non-singing periods (Table 14). The correlations were not as strong as the three-day totals, but there were mostly moderate correlations that moved in the same direction as the full-day totals. There was a significant correlation between non-singing pitch strength and non-singing Dd.

Table 14

Pearson Correlations Between Three Day Non-Singing Doses and Non-Singing Voice Quality

Measure: Non-Singing Periods		Total Non-Singing Dt	Total Non-Singing Dc	Total Non-Singing Dd
dB SPL	*r*	.381	.154	
	p	.107	.528	
Pitch strength	*r*	.505	.263	**.594**
	p	.027	.277	.007
HNR	*r*	.484	.431	.519
	p	.036	.065	.023
Jitter	*r*	-.439	-.492	-.458
	p	.060	.032	.049
Shimmer	*r*	-.513	-.272	-.481
	p	.025	.260	.037

Note. $p < .01$ is indicated in boldface.

Research Question 2: Changes In Voice Quality During Vocal Tasks

I asked if there would there would be statistically significant differences across time in each of ten measures of voice quality (F_0, $P_{0,}$ dB SPL, LTAS slope, alpha ratio, dB SPL 1-3 kHz, pitch strength, shimmer, jitter, and harmonic-to-noise ratio) acquired with the VoxLog collar's acoustic neck microphone (a) between the mean morning, afternoon, and evening measurements of singing and speaking vocal tasks and (b) between a baseline reading of speaking and singing vocal tasks and mean readings of these vocal tasks acquired during three days of monitoring.

Each student completed sets of four vocal tasks at a baseline meeting and at three intervals during each day of ambulatory monitoring: morning, afternoon and evening. Thirteen participants ($N = 13$) successfully completed and recorded all sets of tasks during a baseline and each of three days of ambulatory monitoring (a total of 10 repetitions) at a minimum interval of four hours between each set of tasks each day ($N = 130$ sets of tasks). Table 15 presents the mean results of each task for men ($n = 7$) and women ($n = 6$).

Table 15

Vocal Tasks Results – Measures of Central Tendency by Sex

Measure	Spoken /a/		Sung /a/		Amazing Grace		Rainbow Passage	
	M *n*=7	W *n*=6	M *n*=7	W *n*=6	M *n*=7	W *n*=6	M *n*=7	W *n*=6
F_0 Mean (Hz)	135.49	234.17	167.12	358.31	174.85	332.63	118.45	240.05
F_0 Median	134.90	234.54	164.40	358.33	166.46	313.08	113.17	228.97
F_0 Mode	134.78	231.50	164.07	354.05	162.24	305.32	108.63	210.82
F_0 St Dev	4.32	13.72	6.48	6.53	39.42	72.65	32.67	50.71
P_0 Mean (Hz)	132.00	239.81	167.41	357.81	170.75	332.97	120.43	243.68
P_0 Median	131.74	240.25	167.98	358.61	162.71	313.96	112.19	231.18
P_0 Mode	131.80	239.55	166.77	359.95	159.57	302.02	106.87	214.15
P_0 St Dev	6.56	12.03	9.43	8.91	41.42	72.95	46.05	55.94
PS Mean (%)	57.97	59.04	60.00	67.26	63.85	66.77	45.37	50.70
PS St Dev	5.61	6.21	5.52	6.29	13.90	12.74	16.52	18.55
dB SPL Mean	70.39	62.06	73.08	66.10	71.22	65.75	66.56	63.68
dB St Dev	3.15	3.14	3.48	3.68	6.84	6.54	7.75	7.30
Alpha ratio	-21.26	-19.57	-20.88	-16.11	-24.88	-23.90	-25.21	-24.72
dB 1-3kHz	-58.10	-59.63	-60.70	-64.25	-47.98	-50.01	-47.19	-43.70
Jitter %	0.32	0.36	0.31	0.23	NA	NA	NA	NA
Shimmer %	3.09	4.17	2.56	2.82	NA	NA	NA	NA
HNR	23.46	22.87	25.20	28.44	NA	NA	NA	NA
Duration (s)	8.65	9.30	8.83	9.43	30.04	32.19	27.48	28.36

Changes from morning to evening. I analyzed each individual's three-day mean for each set of tasks for changes from morning to afternoon, from morning to evening and from afternoon to evening. I completed analyses of changes because they usually have preferred statistical properties for use in classical statistical procedures compared to raw data. I adjusted the logarithmic frequency readings of F_0 and P_0 to semitones so that men and women could be analyzed as a single group. I employed one-way repeated measures ANOVAs comparing the morning, afternoon and evening readings for each recorded day ($N = 39$, three days each for 13 participants) (Table 16).

Table 16

One-Way Repeated Measures ANOVA: Time of Day Changes in Voice Quality Measures for Four Vocal Tasks

Task	Measure	Mor *M(SD)*	Aft *M(SD)*	Eve *M(SD)*	*df 1*	*df2*	*F*	*p*
Spoken /a/	Semitone (F_0)	18.74 (6.89)	20.17 (6.89)	19.74 (6.27)	2	76	5.81	**.005**
	Semitone (P_0)	19.06 (6.98)	20.17 (6.10)	19.78 (6.24)	2	76	4.04	.022
	dB SPL	65.24 (6.52)	67.07 (5.72)	66.72 (7.92)	2	76	3.83	.026
	LTAS Slope (X100)	-.77 (.17)	-.77 (.15)	-.73 (.15)	2	76	1.89	.158
	Alpha ratio*	-21.66 (3.73)	-20.71 (4.77)	-19.81 (3.33)	1.74	66.0	3.73	.035
	dB SPL 1-3 kHz	-57.69 (4.32)	-57.47 (5.52)	-57.34 (4.87)	2	76	0.11	.893
	PS Mean	58.18 (8.22)	58.72 (8.73)	58.80 (9.32)	2	76	0.13	.881
	Jitter %	0.37 (0.2)	0.33 (0.2)	0.35 (0.2)	2	76	0.39	.678
	Shimmer %	3.98 (2.5)	3.41 (2.3)	3.76 (2.8)	2	76	0.58	.562
	HNR	22.17 (4.73)	23.36 (3.73)	23.25 (5.59)	2	76	1.03	.363
Sung /a/	Semitone (F_0)	23.61 (8.41)	25.32 (8.44)	25.12 (7.94)	2	76	6.74	**.002**
	Semitone (P_0)	23.61 (8.43)	25.31 (8.43)	25.13 (7.89)	2	76	6.79	**.002**
	dB SPL	68.44 (7.03)	70.67 (6.38)	69.74 (7.58)	2	76	5.01	**.009**
	LTAS slope (x100)	-.69 (.18)	69 (.0016)	-.65 (.16)	2	76	1.31	.275
	Alpha ratio	-20.35(6.79)	-18.67(6.07)	-18.04(4.83)	2	76	4.55	**.014**
	dB SPL 1-3 kHz	-62.51(5.75)	-62.66(6.19)	-61.69(6.42)	2	76	0.89	.416
	PS Mean	63.50 (9.59)	63.23 (9.03)	63.63 (9.96)	2	76	0.08	.923
	Jitter %	0.32 (0.20)	0.26 (0.17)	0.28 (0.18)	2	76	1.51	.227
	Shimmer %	3.0 (1.7)	2.8 (2.2)	2.5(1.2)	2	76	1.43	.245
	HNR	25.77 (5.26)	27.01(5.70)	26.75(5.38)	2	76	1.46	.238

(table continues)

Task	Measure	Mor *M(SD)*	Aft *M(SD)*	Eve *M(SD)*	*df 1*	*df2*	*F*	*p*
Amazing Grace	Semitone (F_0)	24.31 (6.67)	25.50 (6.01)	25.47 (5.42)	1.47	24.3	6.76	**.005**
	Semitone (P_0)	24.10 (6.81)	25.19 (6.24)	24.93 (5.63)	1.51	16.8	5.39	.013
	dB SPL	67.66 (5.50)	69.68 (4.71)	68.31 (5.41)	2	76	7.45	**.001**
	LTAS slope (x100)	-.87 (.12)	-.89 (.12)	-.85 (.11)	2	76	3.12	.050
	Alpha ratio	-25.71(2.43)	-25.13(2.86)	-24.19(2.81)	2	76	7.92	**.001**
	dB SPL 1-3 kHz	-50.53(3.98)	-48.41(3.41)	-48.58(3.53)	2	76	12.08	**<.001**
	PS Mean	64.75 (5.47)	65.72 (4.71)	65.05 (5.55)	2	76	0.64	.529
Rainbow Passage	Semitone (F_0)	17.95 (6.80)	19.50(6.41)	18.95(6.44)	2	76	43.04	**<.001**
	Semitone (P_0)	18.36 (6.85)	19.68 (6.34)	19.24 (6.41)	2	76	33.26	**<.001**
	dB SPL	64.58 (4.92)	66.17 (4.30)	64.86 (4.72)	2	76	5.16	**.008**
	LTAS slope (x100)	-.85 (.14)	-.86 (.13)	-.82 (.13)	2	76	2.15	.123
	Alpha ratio	-25.37(2.13)	-25.06(1.60)	-24.88(2.04)	2	76	0.78	.463
	dB SPL 1-3 kHz	-46.08(3.38)	-45.51(3.52)	-45.67(3.55)	2	76	0.68	.511
	PS Mean	46.67 (6.24)	48.76 (5.07)	47.90 (5.27)	2	76	3.37	.040

Note. $p < .01$ is indicated in boldface. *For those variables that violated the assumption of sphericity based on Mauchly's test for sphericity ($p < .05$), a Greenhouse-Geisser correction was applied.

Post hoc pairwise comparisons using Least Significant Difference *t*-tests of the spoken /a/ tasks revealed significant changes in semitone derived from both F_0 ($p = .009$)and P_0 ($p = .013$) between morning and afternoon, and a slight decrease from afternoon to evening. The changes from afternoon to evening and morning to evening were not significant for or P_0. Likewise dB SPL rose significantly from morning to afternoon (an increase of 1.83±0.65 dB SPL, $p = .007$), but there was not a significant change from afternoon to evening (a decrease of 0.35±0.73 dB SPL, $p = .005$), and because dB returned toward the morning levels, there was not a significant difference between morning and evening (1.47±0.73 dB SPL, $p = .049$). Alpha ratio continued to increase throughout the day. The morning to afternoon change was not significant (an increase of 0.97±0.79, $p = .234$), but the morning to evening change was (an increase of 1.87±.56, $p = .002$). The ANOVA was repeated for both male days of monitoring ($n = 21$) and female days of monitoring ($n = 18$) in separate groups, the only difference in significance being that taken as separate groups, there were no longer significant changes in alpha ratio for either men ($p = .024$) or women ($p = .038$)

Post hoc pairwise comparisons using Least Significant Difference *t*-tests of the sung /a/ tasks revealed significant changes in semitone derived from both F_0 ($p < .001$) and P_0 ($p = .001$) between morning and afternoon ($F_{0:}$ 23.61±1.35 *vs.* 25.32 ± 1.36 and $P_{0:}$ 23.61±1.35 *vs.* 25.34±1.35, respectively), and a negligible decrease from afternoon to evening (25.12±1.27, $p > .999$ for semitone derived from F_0 and 25.14±1.26, $p > .999$ for semitone derived from P_0). While changes from afternoon to evening and morning to evening were not significant, significant changes remained between morning and evening for both for F_0 ($p = .010$) and P_0 ($p = .009$). Likewise dB SPL rose significantly from morning to afternoon (an increase of 2.23±0.65 dB SPL, $p = .001$), but there was not a significant change from afternoon to evening (an decrease of 0.93±0.69 dB SPL, $p = .183$), and because dB returned toward the morning levels, there was not a significant difference between morning and evening (an increase of 1.29±0.77 dB SPL, $p = .104$). Alpha ratio continued to increase throughout the day. The morning to afternoon change was not significant (an increase of 1.67±0.75, $p = .031$), but the morning to evening change was significant (an increase of 2.30±0.77, $p = .005$).

I repeated one-way repeated measures ANOVAs on the sung /a/ task for separate groups of men and women and found several differences between the sexes. Men ($n = 21$) demonstrated significant results in exactly the same areas as the full group. Women ($n = 18$) showed fewer significant results than the entire group, with no significant changes for F_0, $F(2,34) = 1.34$, $p = .276$, P_0, $F(2,34) = 1.26$, $p = .296$, dB SPL, $F(2,34) = 1.60$, $p = .216$, or alpha ratio $F(2.34) = 0.326$, $p = .724$. However, women did have significant changes in jitter, $F(2,34) = 4.71$, $p = .016$, with a 1% increase from morning to afternoon ($p = .011$).

Post hoc pairwise comparisons using Least Significant Difference *t*-tests of the Amazing Grace tasks revealed significant increases in semitone from F_0 ($p < .001$)and semitone from P_0 ($p < .001$) between morning and afternoon and a slight decrease from afternoon to evening. The changes from afternoon to evening and morning to evening were not significant for F_0 ($p = .907$ and $p = .018$ respectively) or P_0 ($p = .378$ and $p = .063$ respectively). Likewise dB SPL rose significantly from morning to afternoon ($p < .001$), but it also decreased significantly from afternoon to evening ($p = .005$), so that there was not a significant difference between morning and evening ($p = .004$). Finally, both alpha ratio ($p < .001$) and dB SPL 1-3 kHz ($p < .001$) also rose significantly from morning to afternoon, but stayed at an elevated level from afternoon to evening: alpha ratio ($p = .298$) and dB 1k to 3K ($p = .230$). The evening levels remaining significantly higher than the morning: alpha ratio ($p = .001$) and dB 1k to 3K ($p < .001$). The ANOVA was repeated for both male days of monitoring ($n = 21$) and female days of monitoring ($n = 18$) in separate groups, the only difference being that taken as separate groups, there were no longer significant changes in alpha ratio for women $F(2,34) = 2.85$, $p = .072$.

Post hoc pairwise comparisons using Least Significant Difference *t*-tests of the Rainbow Passage tasks revealed significant changes at all times of day for semitone derived from both F_0 and P_0, with significant increases from morning to afternoon and significant decreased from afternoon to evening (Table 17). A one-way repeated measures ANOVA was repeated on the

Rainbow Passage task for separate groups of men (*n* = 21) and women (*n* = 18) and revealed the same differences as the overall group.

Table 17

Changes in Semitone between Morning, Afternoon and Evening Rainbow Passage Tasks

Measure	(I) time	(J) time	Mean Difference (I-J)	Std. Error	Sig.[b]
Change in Semitones (from $F_{0)}$	Morning	Afternoon	-1.537	.171	**<.001**
		Evening	-.994	.173	**<.001**
	Afternoon	Morning	1.537	.171	**<.001**
		Evening	.544	.159	**.002**
	Evening	Morning	.994	.173	**<.001**
		Afternoon	-.544	.159	**.002**
Change in Semitones (from $P_{0)}$	Morning	Afternoon	-1.318	.156	**<.001**
		Evening	-.885	.188	**<.001**
	Afternoon	Morning	1.318	.156	**<.001**
		Evening	.433	.148	**.006**
	Evening	Morning	.885	.188	**<.001**
		Afternoon	-.433	.148	**.006**

Note. Based on estimated marginal means. $p < .01$ is indicated in boldface. [b]Least Squared Differences *t*-tests.

Because the focus of this study was on student singers, I observed the individual morning to evening readings by participants during the Amazing Grace singing task for changes in semitone from P_0 (Figure 10), pitch strength (Figure 11), dB SPL (Figure 12), alpha ratio (Figure 13), and dB SPL 1-3 kHz (Figure 14). All but one participant increased the perceived pitch at which Amazing Grace was sung between morning and afternoon. However, perceived pitch decreased morning to evening and afternoon to evening for six of thirteen participants (46%), and five of those six were among the six women for whom the tasks were analyzed.

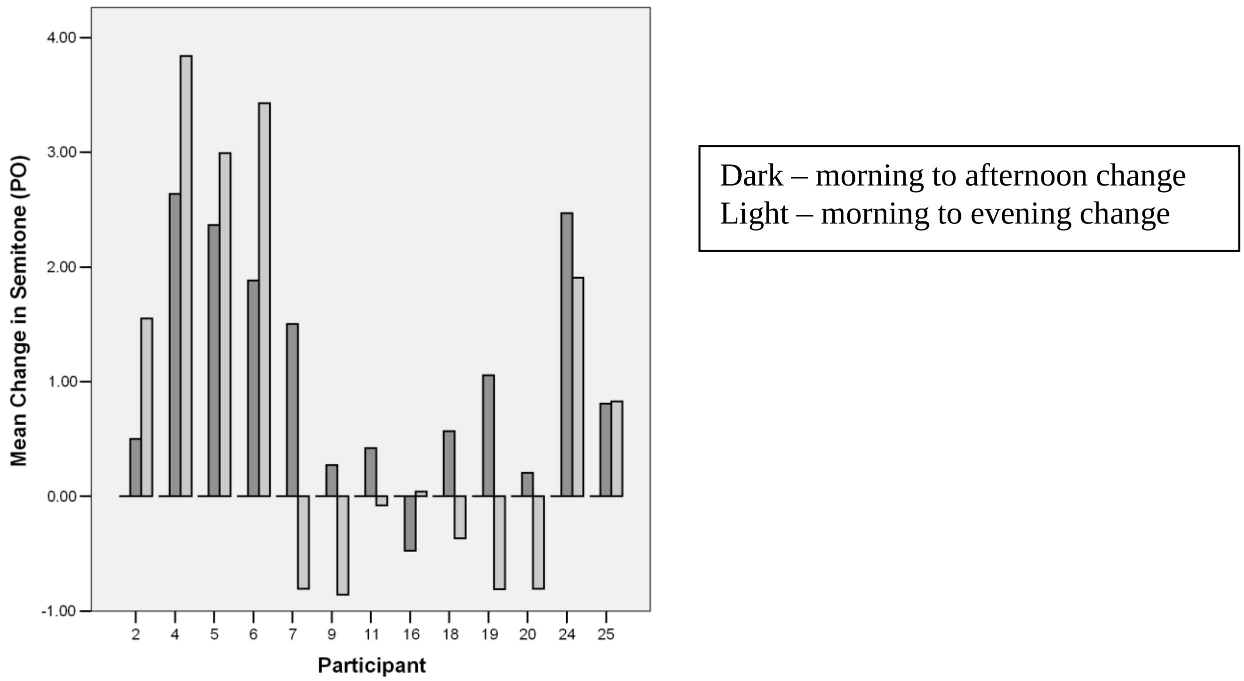

Figure 10. Time of day changes during Amazing Grace singing task: Semitone.

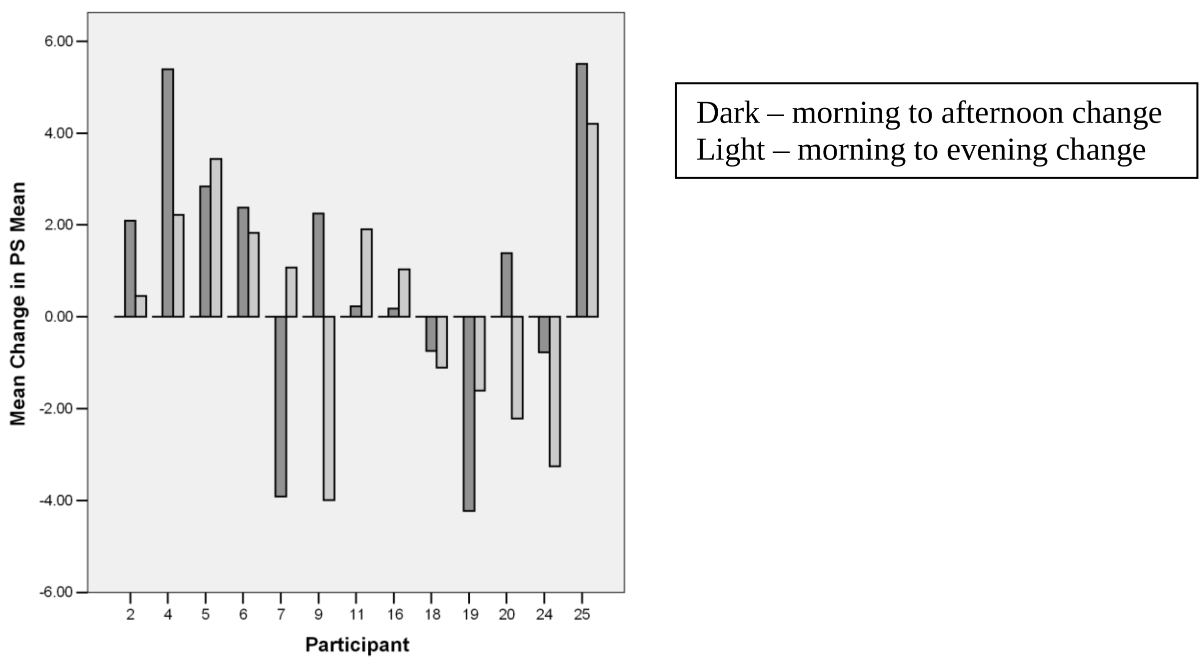

Figure 11. Time of day changes during Amazing Grace singing task: pitch strength.

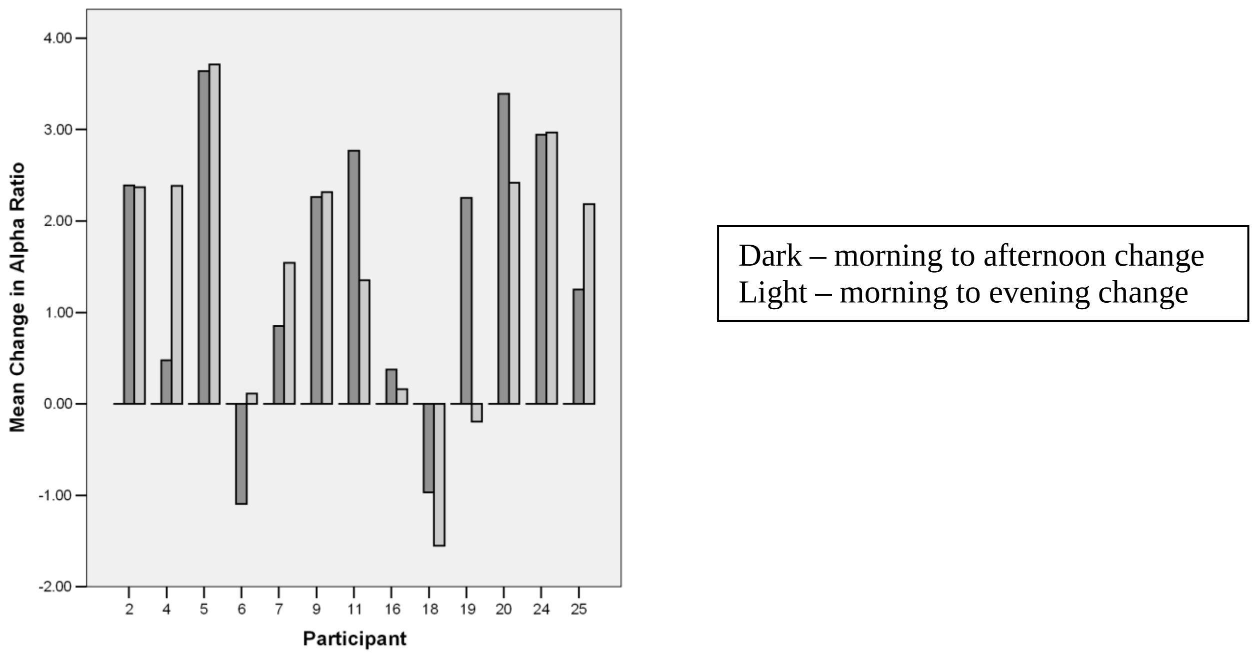

Figure 12. Time of day changes during Amazing Grace singing task: alpha ratio.

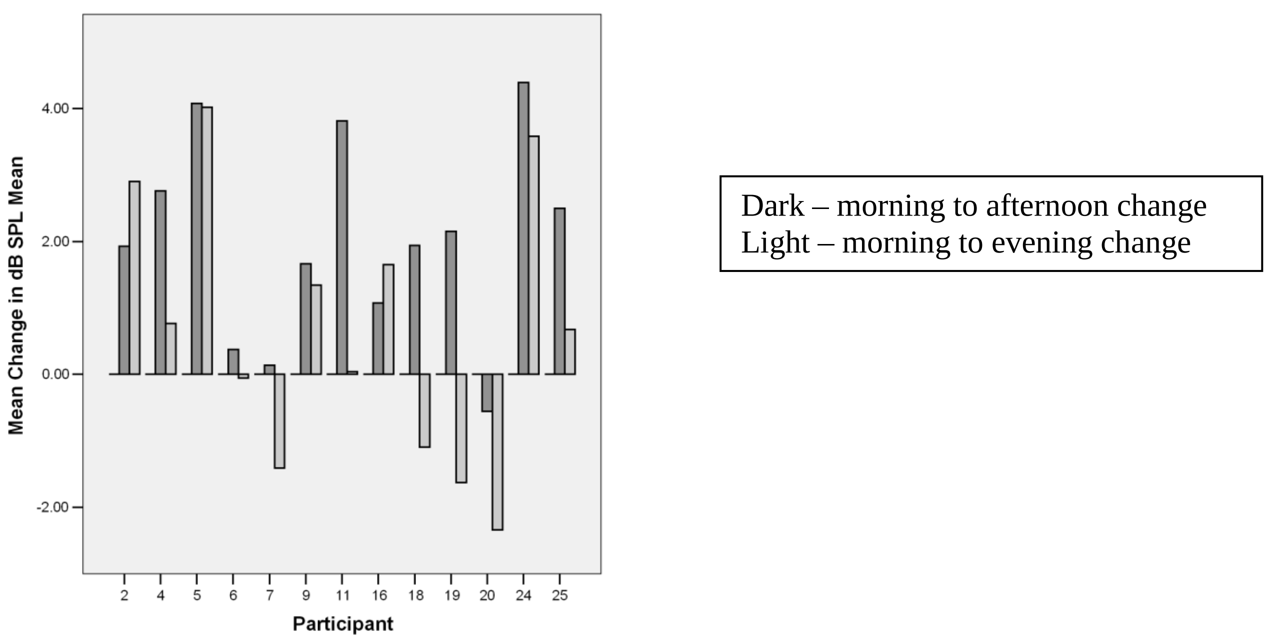

Figure 13. Time of day changes during Amazing Grace singing task: dB SPL.

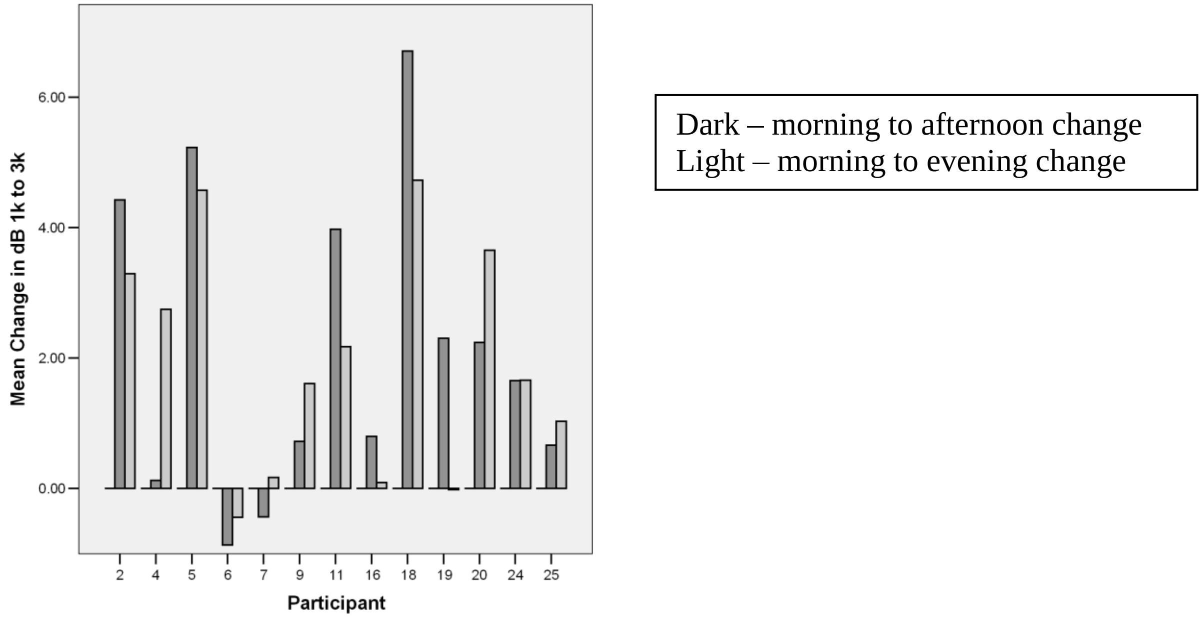

Figure 14. Time of day changes during Amazing Grace task: dB SPL 1-3 kHz.

Figure 15, Figure 16, Figure 17, and Figure 18 demonstrate the daily changes from the morning mean scores. The y-axis in each figure represents the raw change in the mean score for each variable (Semitone for P_0 and $F_{0,}$ *P* for pitch strength, dB for SPL, and the change in ratio for alpha ration and HNR).

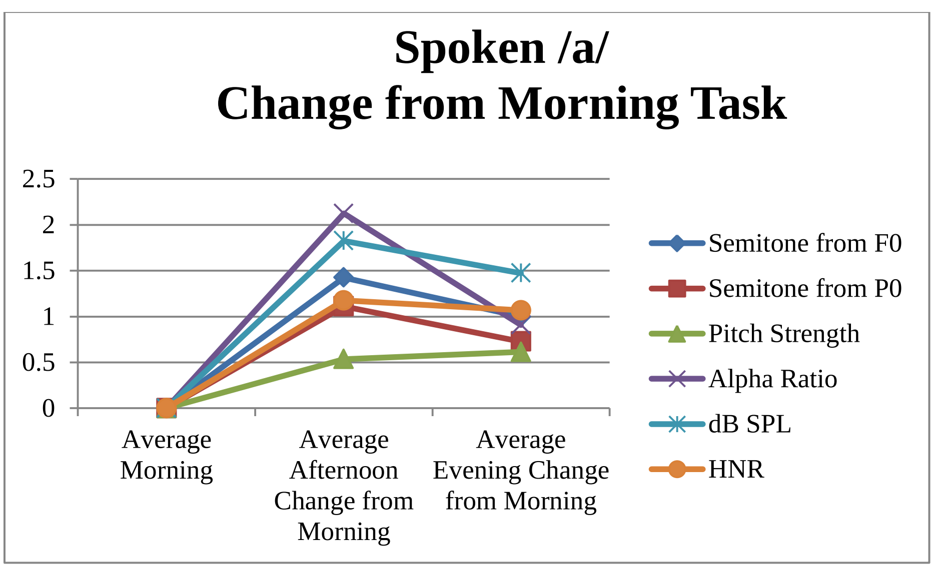

Figure 15. Spoken /a/: Change from morning task.

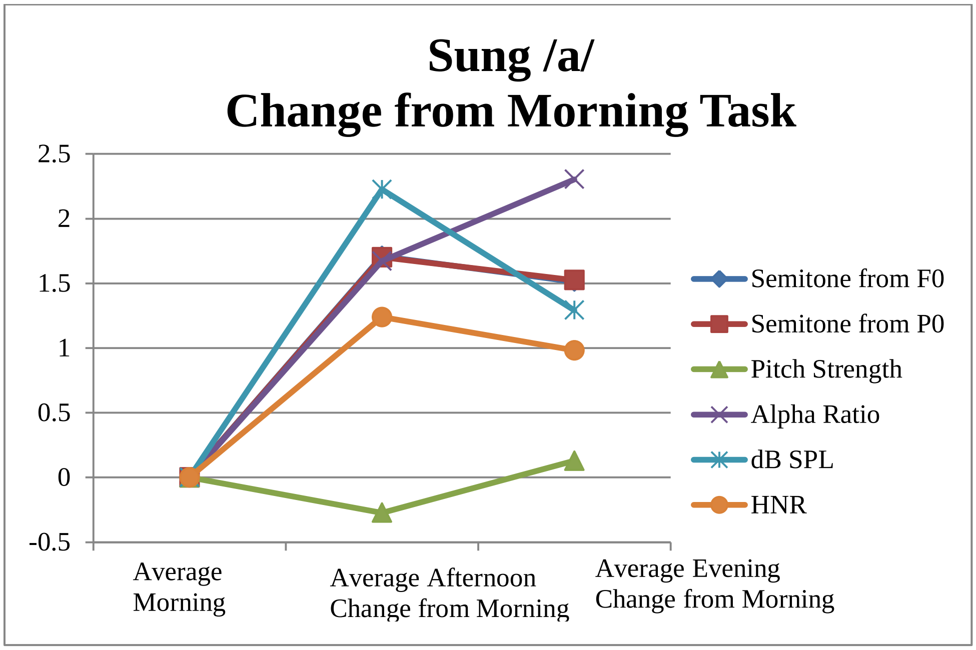

Figure 16. Sung /a/: Change from morning task.

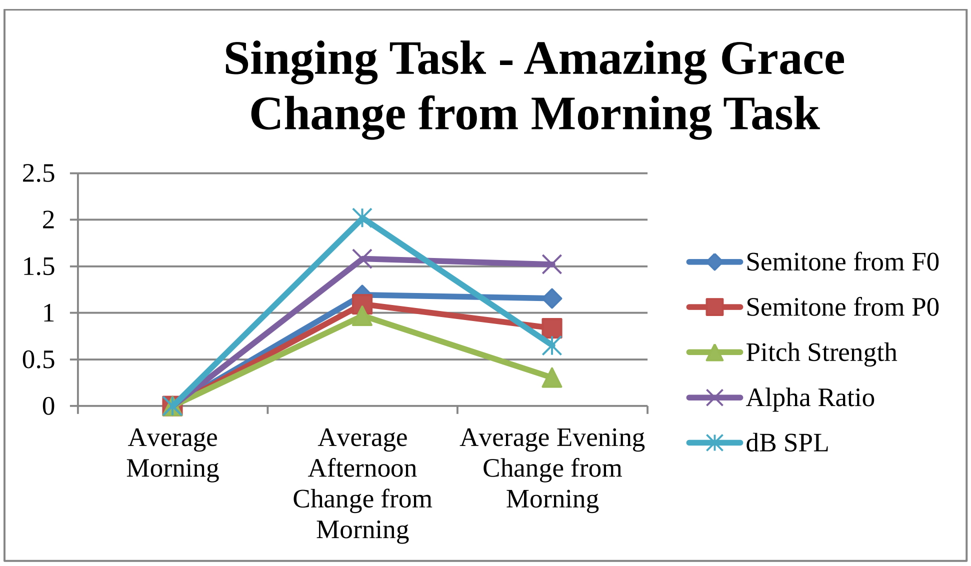

Figure 17. Amazing Grace: Change from morning task.

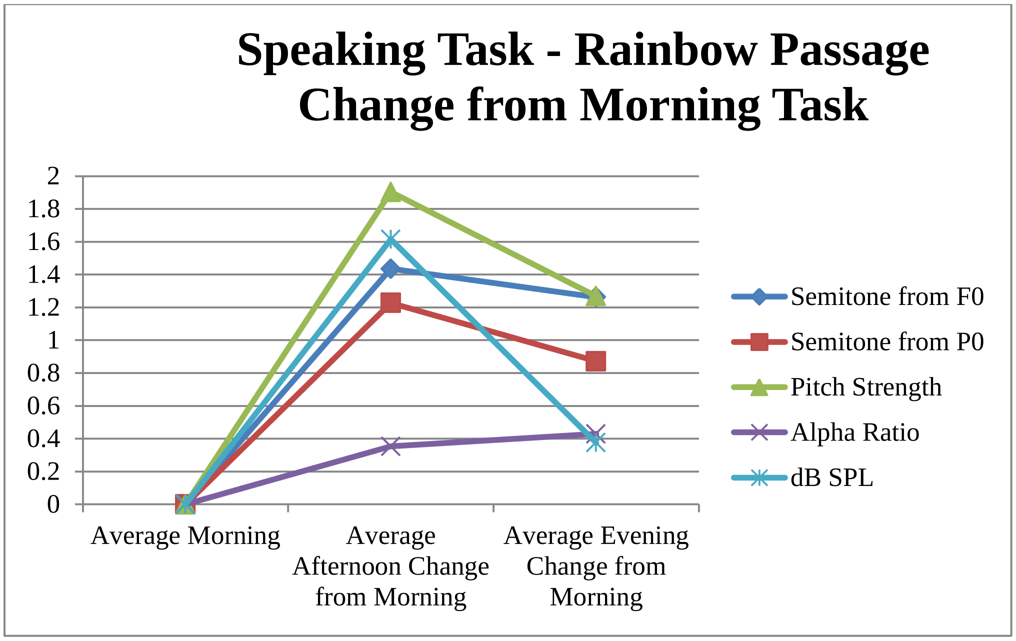

Figure 18. Rainbow Passage: Change from morning task.

Changes from baseline tasks to final tasks. I also analyzed the vocal tasks for daily changes from the baseline through the third day of monitoring. Two of the thirteen participants completing all tasks in the appropriate time-frame had non-consecutive days included in their data sets, so the number of participants for this analysis was reduced to N = 11. I applied repeated measures ANOVAs between the baseline task and the mean tasks reading for each of the three monitoring days for each of the ten measures of voice quality referenced above. I completed this analysis for each of the four vocal tasks. Results of these tests are found in Table 18.

Table 18

Repeated Measures ANOVAs - Daily Tasks Readings

Task	Measure	*M (SD)* Pre	Day 1	Day 2	Day 3	*df 1*	*df2*	*F*	*p*
Spoken /a/									
	Semitone (F_0)	18.74 (6.94)	20.89 (6.23)	20.01 (6.60)	19.55 (6.80)	3	30	3.51	.027
	Semitone (P_0)	18.74 (6.90)	20.91 (6.23)	20.05 (6.57)	19.84 (6.99)	2.00	20.04	3.50	.050
	dB SPL Mean	68.06 (4.59)	67.64 (5.11)	66.06 (6.86)	66.21 (6.69)	1.94	19.35	1.08	.358
	LTAS Slope (x100)	-0.55 (.32)	-0.73 (.10)	-0.76 (.13)	-0.75 (.15)	1.26	12.64	5.13	.035
	Alpha ratio	-16.84 (5.84)	-19.76 (3.20)	-20.43 (2.53)	-20.75 3.42)	1.37	13.65	2.82	.108
	dB SPL 1-3 kHz	-56.76 (3.36)	-57.61 (3.17)	-58.28 (3.75)	-57.60 (4.25)	1.96	19.63	.75	.483
	Pitch strength	57.78 (3.36)	59.33 (3.17)	61.30 (3.75)	58.53 (4.25)	3	20.04	1.34	.279
	Shimmer (%)	2.40 (1.10)	3.60 (1.40)	3.00 (1.00)	3.70 (2.00)	3	30	3.11	.041
	Jitter (%)	0.24 (<.19)	0.31 (.14)	0.33 (.13)	0.35 (<.19)	3	30	2.59	.071
	HNR	25.56 (3.89)	23.93 (2.85)	24.16 (3.39)	22.44 (3.24)	3	30	3.19	.038
Sung /a/									
	Semitone (F_0)	25.24 (7.90)	17.76 (5.67)	18.98 (5.36)	19.22 (5.37)	1.24	12.35	5.00	.038
	Semitone (P_0)	25.20 (7.83)	17.81 (5.66)	19.05 (5.32)	19.22 (5.44)	1.24	12.35	4.97	.039
	dB SPL Mean	71.90 (5.02)	69.75 (5.36)	69.18 (6.88)	69.67 (7.57)	3	30	1.68	.193
	LTAS Slope (x100)	-.55 (.19)	-.68 (.14)	-.67 (.13)	-.66 (.17)	3	30	7.42	**.001**
	Alpha ratio	-14.60 (5.49)	-18.86 (5.59)	-18.65 (4.34)	-18.32 (5.48)	3	30	8.35	**<.001**
	dB SPL 1-3 kHz	-61.92 (5.41)	-61.69 (5.66)	-62.80 (5.89)	-62.12 (5.54)	3	30	0.35	.787
	Pitch strength	63.44 (6.35)	64.33 (7.61)	65.10 (9.13)	64.57 (8.16)	3	30	0.30	.825
	Shimmer %	1.92 (1.15)	2.82 (1.34)	2.20 (0.72)	3.16 (1.86)	3	30	3.79	.020

(table continues)

Task	Measure	*M (SD)* Pre	Day 1	Day 2	Day 3	*df 1*	*df2*	*F*	*p*
	HNR	28.50 (4.72)	26.38 (5.12)	27.25 (5.24)	26.14 (5.05)	3	30	1.40	.263
Amazing Grace									
	Semitone (F_0)	25.62 (5.99)	65.14 (62.06)	65.05 (61.81)	62.62 (57.37)	1.02	10.20	3.90	.075
	Semitone (P_0)	25.31 (6.14)	64.62 (61.62)	64.70 (61.67)	62.86 (58.34)	1.02	10.18	3.92	.075
	dB SPL Mean	69.65 (3.59)	68.63 (3.50)	68.03 (5.37)	68.27 (5.39)	1.51	15.08	0.97	.378
	LTAS Slope (x100)	-0.83 (0.11)	-0.87 (0.12)	-0.87 (0.11)	-0.88 (0.10)	1.49	14.95	3.36	.073
	Alpha ratio	-21.68 (3.06)	-24.52 (2.30)	-24.63 (1.90)	-24.66 (2.68)	1.61	14.95	9.13	**.003**
	dB SPL 1-3 kHz	-46.20 (3.36)	-48.88 (3.26)	-49.52 (3.37)	-49.16 (3.94)	1.28	12.85	4.17	.054
	Pitch strength	66.21 (3.35)	65.14 (3.90)	66.80 (3.10)	65.30 (3.59)	3	30	.88	.461
Rainbow Passage									
	Semitone (F_0)	19.20 (6.29)	46.40 (39.03)	46.24 (38.75)	46.81 (39.75)	1.00	10.02	4.36	.063
	Semitone (P_0)	19.34 (6.33)	46.79 (39.45)	46.79 (39.36)	46.88 (39.39)	1.00	10.02	4.37	.063
	dB SPL Mean	65.31 (2.91)	65.65 (3.55)	64.85 (5.00)	65.22 (4.99)	1.87	18.66	.19	.810
	LTAS Slope (x100)	-0.80 (0.14)	-0.85 (0.12)	-0.85 (0.11)	-0.86 (0.12)	3	30.00	4.97	**.006**
	Alpha ratio	-23.44 (2.04)	-24.70 (1.64)	-25.10 (1.54)	-25.37 (1.03)	3	30.00	6.99	**.001**
	dB SPL 1-3 kHz	-43.59 (2.18)	-44.58 (2.47)	-45.86 (2.45)	-45.87 (2.63)	1.46	14.55	4.15	.048
	Pitch strength	48.30 (5.22)	47.74 (4.78)	48.60 (4.94)	47.77 (3.97)	3	30.00	.60	.618

Note. Significance at the 0.01 level is indicated in bold. Greenhouse-Geisser corrections are applied to those variables that did not meet Mauchly's Test of Sphericity at a significance level of .05.

Post hoc pairwise comparisons of the tasks using Least Significant Difference *t*-tests revealed that all of the significant and nearly significant changes in LTAS slope and alpha ratio occurred between the basline administration of the task and the mean score of the monitoring days in all four tasks:

- **sung /a/:** LTAS slope Baseline - Day 1 (p = .007), LTAS slope Baseline - Day2 (p = .002), LTAS slope Baseline - Day3 (p = .010), alpha ratio Baseline - Day 1 (p = .002), alpha ratio Baseline - Day2 (p = .004) , and alpha ratio Baseline - Day3 (p = .010)
- **Amazing Grace:** alpha ratio Baseline - Day 1 (p = .009), alpha ratio Baseline - Day2 (p = .009) , and alpha ratio Baseline - Day3 (p = .006)
- **Rainbow Passage:** LTAS slope Baseline - Day 1 (p = .024), LTAS slope Baseline - Day2 (p = .014), LTAS slope Baseline - Day3 (p = .001), alpha ratio Baseline - Day 1 (p = .025), alpha ratio Baseline - Day2 (p = .007), and alpha ratio slope Baseline - Day3 (p = .006).

Research Question 3: EASE Questionnaire Results

With the third research question, I inquired about the perceived singing voice function of the participants. I calculated descriptive statistics for the EASE scores, including the three subset scores, among those participants completing three full days of 10.5 more hours of monitoring (N = 19), analyzing the combined survey administrations over four days (N = 76). The possible score range for the survey was 22 to 88, with a lower number indicating greater perceived ease in singing (Table 19).

Table 19

EASE Questionnaire Results – Daily Totals. N = *76*

	Total EASE Score	Subset 1 Score	Subset 2 Score	Emotion Score
M	33.79	16.91	14.42	2.49
Mdn	34.00	16.00	15.00	2.00
Mode	22.00	10.00	10.00	2.00
SD	8.57	5.15	3.87	0.83
Var	73.48	26.49	15.10	0.68
Range	31.00	20.00	17.00	2.00

I analyzed the EASE scores for differences among various groups. Two-tailed independent samples *t*-tests showed differences between the scores of men and women, but those results were not significant at a .01 confidence level. Analyzed scores included total EASE scores (Male, n = 44, M = 31.95, SD = 8.22; Female, n = 32, M = 36.31, SD = 8.53, $t(74)$ = -2.25, p = .028), Subset 1 (Male, n = 44, M = 16.05, SD = 4.81; Female, n = 32, M = 18.09, SD = 5.39, $t(74)$ = -1.73, p =.087), Subset 2 (Male, n = 44, M = 13.57, SD = 3.80; Female, n = 32, M = 15.59, SD = 3.75, $t(74)$ = -2.31, p = .024), and Emotion (Male, n = 44, M = 2.39, SD = 0.75; Female, n = 32, M = 2.63, SD = 0.91, $t(74)$ = -1.25, p = .215), with men scoring lower than women in each comparison.

I employed Pearson correlation tests to test the relationships between EASE scores and students' demographic information (Table 20), with significant positive relationships between years in choir and the emotion subset. This means that among this group of participants, increased choral experience was a significant indication of decreased ability to sing easily.

Table 20

Pearson Correlation Tests Between Mean EASE Scores and Demographics

Variable	EASE Score	Subset 1 Score	Subset 2 Score	Emotion Score
Age	.224	.224	.184	.046
Number of semesters enrolled in college	.035	.039	.037	-.077
Number of years in choir	**.284**	.262	.190	**.410**
Number of years of voice lessons completed	.131	.128	.086	.122

Note. p < .01 is indicated in boldface. N = 76 with four administrations of each EASE survey by each of 19 individuals.

EASE score changes. I employed two statistical methods to determine if perceived changes in vocal efficiency occurred during the study period. First, I completed a two-tailed paired t-test of the baseline EASE score (prior to the three monitoring days) and the final administration of the EASE survey on day three to see if there were significant changes. This test showed essentially no overall difference for the total EASE scores, $t(18) = -.259$, $p = .799$, or either of the main subsets: Subset one, $t(18) = -.784$, $p = .443$; Subset 2, $t(19) = -.161$, $p = .874$. Second, I completed a one-way repeated measures ANOVA with the test's four different administrations as the independent variable and EASE scores as the dependent variable. This also showed no significant change, either in terms of the total EASE score, $F(3, 48) = .419$, p = .740, or the three subset scores: Subset One, $F(3, 48) = .318$, $p = .812$; Subset Two , $F(3, 48)$ = .281, $p = .839$; or, the Emotion subset, $F(3, 48) = .299$, $p = .040$.

Research Question 4: Correlations Between Perception (EASE Scores), Demographics, Vocal Dose and Voice Quality Measures.

I explored the interactions between ambulatory monitoring data acquired with an accelerometer, vocal tasks data acquired with an audio microphone, students' perceived singing voice function, and demographics with the fourth research question. This exploration included the following sub-research questions:

4A. Are there significant correlations between student EASE scores and each of 14 measures of vocal dose and voice quality acquired through ambulatory monitoring?

4B. Are there significant correlations between student EASE scores and each of 10 measures of voice quality acquired through the repeated administrations of four vocal tasks?

4C. Are there significant correlations between students' demographic information (sex, age, years of singing experience, and years of choral experience) and each of 14 measures of vocal dose and voice quality acquired through ambulatory monitoring?

4D. Are there significant correlations between student's demographic information (sex, age, years of singing experience, and years of choral experience) and each of 10 measures of voice quality acquired through the administration of ten repetitions of four vocal tasks?

4E. Are there significant correlations between each of four measures of vocal dose acquired through ambulatory monitoring and each of ten measures of voice quality acquired through the repeated administration of four vocal tasks?

RQ 4a. Correlations between EASE scores and ambulatory monitoring results. I used Pearson correlation coefficient tests to compare EASE scores to means acquired from the three ambulatory monitoring days for the accelerometer (N = 19). I conducted two different tests. First, I compared the ambulatory monitoring means to the mean four-day EASE score (Baseline, Day 1, Day 2, and Day 3). Then, I compared the ambulatory monitoring means to the change in EASE score between the Baseline and Day 3. Ambulatory monitoring variables included the four vocal dose measures (Voicing %, Dt, Dd, and Dc) and ten measures of voice quality (F_0, P_0, dB SPL, LTAS slope, alpha ratio, dB SPL 1-3 kHz, pitch strength, shimmer, jitter, and harmonic-to-noise ratio) (Table 21). Neither test revealed any significant correlations between EASE scores and vocal dose or voice quality.

Table 21

*Pearson Correlation Coefficient Tests Between EASE Scores and Voicing Measures Acquired During Ambulatory Monitoring Days (*N *= 19)*

	Mean 4-Day EASE Score		EASE Score Change from Baseline to Day 3	
Measure	*r*	*p*	*r*	*p*
Voicing %	.073	.766	.055	.822
Dt (min/hr)	.066	.788	.237	.328
Dc (kc/hr)	.350	.142	.091	.712
Dd (m/hr)	.092	.708	.121	.623
F_0	.381	.108	-.069	.778
P_0	.343	.151	-.072	.771
dB SPL	-.064	.794	.002	.992
LTAS slope	.321	.181	.156	.523
Alpha ratio	-.160	.514	.004	.986
dB 1-3kHz	.042	.865	-.070	.775
Pitch strength	-.182	.456	-.243	.316
jitter	-.343	.150	.215	.376
shimmer	.167	.494	.140	.568
HNR	-.330	.167	-.141	.563

RQ 4b. Correlations between EASE scores and vocal tasks results. I completed Pearson correlation coefficient tests between voice quality data acquired during all ten administrations of the vocal tasks (*N* = 130) and the corresponding EASE survey total score for that day. The correlation tests revealed significant correlations between EASE score and

semitone (positive correlation for 3 of four tasks), dB SPL (negative correlation for all four tasks), LTAS slope (a negative correlation for the Rainbow Passage only), alpha ratio (a negative correlation for the two spoken tasks), and pitch strength (a negative correlation for Sung /a/ and a positive correlation for the Rainbow Passage)(Table 22).

Table 22

*Pearson Correlation Coefficient Tests Between EASE Scores and Voice Quality Scores Acquired During Vocal Tasks (*N = *13)*

Voice Quality Measure	Spoken /a/	Sung /a/	Amazing Grace	Rainbow Passage
M Semitone from F_0	**.469**	-.116	**.434**	**.503**
M Semitone from P_0	**.489**	-.115	**.441**	**.502**
M dB SPL	**-.352**	**-.394**	**-.446**	**-.444**
LTAS Slope	.013	.205	-.151	**-.242**
Alpha ratio	**.203**	**.257**	.111	-.005
dB 1k to 3k	.103	.136	-.088	.176
Pitch strength	**-.251**	-.117	-.056	**.243**
Jitter	-.099	.038		
Shimmer	.117	.128		
HNR	.022	-.085		

Note. $p < .01$ is indicated in boldface. $N = 130$ with 10 repetitions of each task by each of 13 individuals.

RQ 4c. Demographic differences in vocal dose and voice quality measures acquired through ambulatory monitoring. I used Pearson correlation coefficient tests to compare each of 14 ambulatory monitoring measures with voice quality and age, semesters in college, years of choir participation, and years of voice lessons (Table 23). I employed a point-biserial correlation coefficient to examine the relationship between voice quality and sex. There were no significant correlations between vocal dose or voice quality and age, years in choir, or years of voice lessons. There were significant correlations between sex and each of three measures: $F_{0,}$ P_0, and

Dc. This was expected as women typically have a higher average phonation pitch than men. There was also a significant correlation between sex and dB SPL 1-3 kHz (*p* = .008), with women having greater spectral energy in this frequency region than men.

Table 23

Correlations Between Demographic Data and Vocal Dose and Voice Quality Data Acquired During Ambulatory Monitoring

	r			
Measure	Sex	Age	Years in Choir	Years Voice Lessons
Voice %	-.438	.288	-.455	.090
Dt	-.439	.247	-.393	.264
Dc	**.544**	.231	.062	.249
Dd	-.317	.200	-.348	.380
P_0	**.954**	.134	.404	.075
F_0	**.938**	.101	.368	.090
dB SPL	-.200	.050	-.237	.372
LTAS slope	.344	.363	.220	.333
Alpha ratio	.265	-.084	-.136	-.261
dB SPL 1-3 kHz	**.587**	-.163	.018	-.023
Pitch strength	-.404	.136	-.415	-.117
Jitter	-.018	-.047	.310	.134
Shimmer	.301	-.126	.433	.061
HNR	-.071	.085	-.328	.011

Note. A point-biserial correlation test was employed for sex, with a positive correlation indicating higher means for women and a negative correlation indicating higher means for men. $p < .01$ is indicated in boldface.

RQ 4d. Demographic differences in voice quality measures acquired through vocal tasks. I analyzed voice quality measures obtained from the 10 vocal tasks administrations acquired by the audio microphone for correlations between demographic categories. I used Pearson correlation coefficient tests to compare voice quality and age, semesters in college, years of choir participation and years of voice lessons. I employed a point-biserial correlation coefficient to examine the relationship between voice quality and sex (Table 24).

Table 24

Correlations Between Demographic Data and Voice Quality Data Acquired During Vocal Tasks.

Voice Quality Measure	Task	Sex	Age	Years in Choir	Years Voice Lessons
M Semitone from F_0	Spoken /a/	**.723**	-.140	.187	.029
	Sung /a/	-.070	.184	.060	**.308**
	Amazing Grace	**.909**	-.039	**.501**	.178
	Rainbow Passage	**.967**	-.108	**.381**	.170
M Semitone from P0	Spoken /a/	**.772**	-.136	.190	.032
	Sung /a/	-.064	.181	.063	**.309**
	Amazing Grace	**.933**	-.080	**.471**	.129
	Rainbow Passage	**.968**	-.108	**.381**	.170
M dB SPL	Spoken /a/	**-.633**	.097	-.072	**-.240**
	Sung /a/	**-.510**	.223	.096	**-.238**
	Amazing Grace	**-.532**	-.060	.078	**-.386**
	Rainbow Passage	**-.319**	-.077	.039	**-.236**
M LTAS slope	Spoken /a/	-.101	**.297**	**.357**	**.368**
	Sung /a/	**.304**	**.365**	**.293**	**.263**
	Amazing Grace	-.210	-.132	.114	-.112
	Rainbow Passage	**-.450**	**-.251**	-.096	-.133
M alpha ratio	Spoken /a/	.193	.133	.093	.124
	Sung /a/	**.396**	**.433**	.150	.191
	Amazing Grace	.169	.014	.184	.037
	Rainbow Passage	.124	-.183	.075	.218
M dB SPL 1-3 kHz	Spoken /a/	.155	**-.237**	**-.339**	**-.231**
	Sung /a/	**-.295**	-.008	**-.530**	**-.176**
	Amazing Grace	**-.270**	-.051	-.213	.023
	Rainbow Passage	**.511**	-.133	.193	.188
M pitch strength	Spoken /a/	.064	**-.281**	-.031	-.123
	Sung /a/	**.392**	.071	**.342**	.020
	Amazing Grace	**.283**	.050	.224	.073
	Rainbow Passage	**.483**	**.229**	.202	-.024
M jitter	Spoken /a/	.081	-.120	-.192	-.144
	Sung /a/	**-.232**	-.176	**-.347**	-.168
M shimmer	Spoken /a/	.223	-.184	.028	.012
	Sung /a/	.075	-.171	**-.191**	.098
M HNR	Spoken /a/	-.062	.128	.014	-.120
	Sung /a/	**.301**	.039	**.443**	-.065

Note. A point-biserial correlation test was employed for sex, with a positive correlation indicating higher means for women and a negative correlation indicating higher means for men. Pearson correlation coefficient tests were employed for the remaining variables. $p < .01$ is indicated in boldface. $N = 130$ with 10 repetitions of each task by each of 13 individuals.

RQ 4e. Relationship between vocal dose and voice quality data from vocal tasks. I used Pearson correlation coefficient tests to explore the relationship between the totals of four vocal dose measures acquired through ambulatory monitoring (voicing %, Dt, Dc, and Dd) and voice quality measures acquired through vocal tasks with the audio microphone (F_0, $P_{0,}$ dB SPL, LTAS slope, alpha ratio, dB SPL 1-3 kHz, pitch strength, shimmer, jitter, and harmonic-to-noise ratio) (Table 25). The ambulatory dose measures were the totals for all three days of monitoring for those who completed the vocal tasks (*N* = 13) and the tasks measures were the aggregated mean totals for all ten administrations of all four vocal tasks for those same individuals. The only significant correlations were between Dc and F_0 and P_0. Cycle dose is partly a function of frequency, however, and these results were likely due to differences in frequency between the sexes.

Table 25

Pearson Correlation Coefficient results between Ambulatory Vocal Dose Totals and Vocal Tasks Voice Quality Means

		r		
Voice Quality Measure	Voicing %	Dt	Dc	Dd
M Semitone from F_0	-.336	-.247	**.698**	-.118
M Semitone from P_0	-.345	-.255	**.694**	-.129
M dB SPL	.019	.087	-.412	.051
LTAS Slope	.196	.182	.572	.255
Alpha ratio	-.068	-.177	-.228	.028
dB SPL 1-3 kHz	.282	.256	.195	.207
Pitch strength	-.440	-.331	.274	-.185
Jitter	.066	-.095	-.281	-.265
Shimmer	-.292	-.416	-.144	-.354
HNR	-.165	.041	.439	.082

Research Question 5. Correlations Between the VoxLog Audio and Accelerometer Transducer Readings.

I compared voice quality readings from the VoxLog collar's accelerometer transducer with its acoustic transducer using the vocal tasks readings. Variables analyzed included F_0, P_0, dB SPL, LTAS slope, alpha ratio, dB SPL 1-3 kHz, pitch strength, shimmer, jitter, and HNR. In order to observe any potential difference between different types of voicing activity, the above variables were measured for all four sets of vocal tasks (spoken/a/, sung /a/, Amazing Grace and Rainbow Passage). The tasks readings were analyzed for the 13 participants, seven men and six women, who completed all ten sets of vocal tasks at appropriate time intervals. These tasks readings constituted 130 data points for each transducer and each task.

First, I analyzed the various readings for percentage agreement and significant differences between the two transducer readings. Two-tailed paired sample *t*-tests were used to examine the significance of the difference in means for each participant. The two transducers showed agreement within 0.5% on three of the four tasks for both P_0 and F_0 and no significant differences in three of the four task means for F_0. However, for the Rainbow Passage, the P_0 mean was 3.37% different and the F_0 mean was 1.15% different, and both showed significant differences in the paired *t*-tests. Full results detailing percentage agreement and two-tailed paired *t*-tests for each variable are detailed in Table 26.

In order to account for different types of voicing that could occur during ambulatory monitoring, I combined the mean readings of each set of 10 tasks for each individual into a larger set of all four tasks together and examined for overall differences with two-tailed paired *t*-tests ($N = 520$). There were significant differences between the two transducer readings at $p < 0.01$ for a majority of the variables. The variables without significant differences were some measures of central tendency related to F_0 (all but *SD*), and pitch strength (mean median and mode, but not *SD*, variance or *IQR*)(**Error! Reference source not found.**).

Table 26

Differences Between Accelerometer and Audio Transducer Readings During Four Vocal Tasks.

	Spoken /a/		Sung /a/		Amazing Grace		Rainbow Passage	
	P agreement audio/acc.	*p*	*P* agreement audio/acc.	*p*	*P* agreement audio/acc.	*p*	*P* agreement audio/acc.	*p*
F_0 *M*	99.71	0.57	100.07	0.61	99.83	0.18	101.14	**0.00**
F_0 *SD*	120.58	0.22	120.00	0.41	100.56	0.34	106.41	0.02
F_0 *var*	191.72	0.10	108.18	0.91	100.65	0.58	105.49	0.35
F_0 Mode	99.24	0.29	98.65	0.13	99.32	0.13	99.77	0.76
F_0 *Mdn*	99.23	0.28	99.45	0.13	99.87	0.31	100.52	0.03
P_0 *M*	99.95	0.40	99.76	**0.00**	99.93	0.25	103.37	**0.00**
P_0 *SD*	161.34	**0.00**	171.88	0.04	101.15	**0.01**	116.66	**0.00**
P_0 *var*	204.08	**0.00**	537.06	0.23	100.56	0.42	128.55	**0.00**
P_0 Mode	99.89	**0.02**	99.81	**0.00**	98.58	**0.04**	101.49	0.04
P_0 *Mdn*	99.84	**0.00**	99.81	**0.00**	99.93	**0.01**	101.66	**0.00**
PS *M*	96.66	**0.02**	100.66	0.63	102.02	**0.01**	98.34	0.02
PS *SD*	94.27	**0.05**	99.13	0.85	112.78	**0.00**	104.74	**0.00**
PS *var*	89.50	0.10	96.44	0.74	127.88	**0.00**	110.11	**0.00**
PS Mode	96.33	**0.01**	100.01	0.99	103.14	**0.00**	101.40	0.32
PS *Mdn*	96.73	**0.02**	100.69	0.61	102.99	**0.00**	99.83	0.85
dB *M*	92.47	**0.00**	93.34	**0.00**	90.18	**0.00**	86.98	**0.00**
dB *SD*	134.41	**0.00**	145.84	**0.00**	132.49	**0.00**	136.43	**0.00**
dB *var*	182.72	**0.00**	225.33	**0.00**	178.35	**0.00**	188.61	**0.00**
dB Mode	92.75	**0.00**	93.89	**0.00**	92.01	**0.00**	89.57	**0.00**
dB *Mdn*	92.78	**0.00**	93.76	**0.00**	91.43	**0.00**	88.72	**0.00**
LTAS slope	99.71	**0.00**	100.07	**0.00**	99.83	**0.00**	101.14	**0.00**
Alpha ratio	120.58	**0.00**	120.00	**0.00**	100.56	**0.00**	106.41	**0.00**
dB 1-3 kHz	191.72	**0.00**	108.18	**0.00**	100.65	**0.00**	105.49	**0.00**
Jitter	60.03	**0.00**	59.32	**0.00**				
Shimmer	72.34	**0.00**	55.56	**0.00**				
HNR	115.57	**0.00**	122.23	**0.00**				

Note. *N* = 130 for each task. Two-tailed significance for paired *t*-tests at the 0.01 level is indicated in bold. *P* values indicate the percentage of agreement between the two transducers. A *P* below 100% indicates a higher mean for the accelerometer readings. A *P* above 100% indicates a higher mean for the audio transducer readings.

Table 27

Differences Between Accelerometer and Audio Transducer Readings: Combined Vocal Tasks

	Paired Differences Audio-Acc				*P* Agreement
	Mean	*SD*	*t*	*p*	Audio/Acc
F_0 *M*	0.30	6.58	1.03	.304	100.14
F_0 *SD*	1.33	12.04	2.53	**.012**	105.05
F_0 *var*	70.24	1149.79	1.39	.164	105.17
F_0 Mode	-1.68	17.21	-2.23	.026	99.18
F_0 *Mdn*	-0.56	9.54	-1.34	.180	99.73
F_0 IQR	2.01	25.86	1.77	.078	106.77
P_0 *M*	1.14	5.51	4.72	**<.001**	100.53
P_0 *SD*	3.78	12.54	6.87	**<.001**	113.76
P_0 *var*	268.91	1929.08	3.18	**.002**	119.01
P_0 Mode	-0.57	11.08	-1.16	.245	99.72
P_0 *Mdn*	0.44	3.04	3.32	**.001**	100.21
P_0 IQR	1.35	18.45	1.66	.097	104.02
Pitch strength *M*	-0.30	7.70	0.83	.406	99.49
Pitch strength *SD*	0.47	2.31	-4.68	**<.001**	104.57
Pitch strength *var*	15.51	49.28	7.18	**<.001**	112.08
Pitch strength Mode	0.18	9.05	0.47	.642	100.28
Pitch strength *Mdn*	0.18	8.46	0.49	.626	100.29
Pitch strength IQR	-0.52	4.33	-2.72	**.007**	95.13
dB SPL *M*	-6.91	6.17	-25.53	**<.001**	90.72
dB SPL *SD*	1.39	1.44	21.99	**<.001**	136.32
dB SPL *var*	15.19	18.19	19.04	**<.001**	187.66
dB SPL Mode	-6.78	10.18	-15.19	**<.001**	90.96
dB SPL *Mdn*	-6.91	9.31	-16.92	**<.001**	90.76
dB SPL IQR	0.10	1.84	1.27	.203	102.29
LTAS Slope (x100)	-0.27	.21	-29.78	**<.001**	155.08
Alpha ratio	-3.06	5.31	-13.13	**<.001**	116.52
dB SPL 1-3 kHz	1.10	7.07	3.56	**<.001**	97.98
Jitter %	- 0.16	0.30	-8.56	**<.001**	65.74
Shimmer %	-2.27	3.43	-10.65	**<.001**	58.02
HNR	3.99	6.12	10.51	**<.001**	119.04
Duration of Task	0.05	1.45	0.77	.444	100.25

Note. $N = 520$. $P < .01$ is indicated in boldface (two-tailed). Probability values indicate the percentage of agreement between the two transducers. A *P* below 100% indicates a higher mean for the accelerometer readings. A *P* above 100% indicates a higher mean for the audio transducer readings.

I then employed regression analysis on these measures to determine the level of prediction that could be employed to predict acoustic source/filter measures of voice quality from VoxLog bio-acoustic accelerometer vocal source data (Table 28). ANOVAs conducted on each regression comparison returned a significance level of $p < .001$. The regression tables showed a standard error of the estimate of 5-6 Hz for the two frequency measures, an error rate well under a semitone for even the lowest spoken or sung pitches. All other measures had an R^2 value of less than .520, indicating that nearly 50% of the results or more for each of these measures were determined by something beyond the corresponding accelerometer reading. In order to determine the extent of the effect the standard errors of estimate could have on the accuracy of each measure's predicted audio score, I divided the standard error of estimate by the mean audio tasks score for each variable. This provided the percentage of the variable's mean score that could be covered by the standard error. The results were 3.07% (F_0), 2.54% (P_0), 7.77% (dB SPL), 19.23% (LTAS slope), 15.67% (alpha ratio), 13.07% (dB SPL 1-3 kHz), 11.74% (pitch strength), 51.61% (shimmer), 51.12% (jitter), and 18.48% (HNR).

Table 28

Regression Table for Determining Audio/Acoustic Results from Accelerometer Data

	r	R^2	β_0	β_0 *SE*	β_1	β_1 *SE*	*Adj.* R^2	Std. Error of the Estimate
F_0	.997	.995	0.683	0.73	0.998	0.003	.996	6.58
P_0	.998	.996	2.89	0.60	0.992	0.003	.996	5.46
dB SPL	.513	.263	31.03	2.70	0.491	0.036	.261	5.25
LTAS slope (x100)	.467	.218	-0.60	0.02	0.363	0.467	.216	0.15
Alpha ratio	.705	.497	-13.13	0.43	0.474	0.021	.496	3.47
dB 1-3kHz	.502	.252	-9.82	3.32	0.800	0.061	.251	7.00
Pitch strength	.720	.518	18.97	1.71	0.674	0.029	.517	6.89
Shimmer %	.653	.426	1.42	0.16	0.318	0.023	.424	1.6
Jitter %	.512	.262	0.18	0.02	0.274	0.029	.259	0.16
HNR	.507	.257	16.53	0.94	0.402	0.042	.254	4.61

Note. N = 520 for $F_{0,}$ $P_{0,}$ pitch strength, dB SPL, alpha ratio and dB SPL 1-3 kHz < .001. N = 260 for shimmer, jitter and HNR as these measures were only acquired for the spoken /a/ and sung /a/ tasks. β_0 refers to the y-intercept and β_1 refers to the slope.

Scatter plots with best fit lines and plots showing 95% confidence intervals of the mean for these data are represented below (Figures 19-29). The regression formula is included in the center of each plot, with the first number representing the y-intercept and the second number representing the slope. The data points were grouped in each scatter plot by task. Because the data were not distributed evenly for LTAS slope, I created a second scatter plot for that variable showing the data points for the Amazing Grace and Rainbow Passage only (Figure 23). This plot revealed that these two tasks had an R^2 of 0.36 and the best fit line went in the opposite direction, indicating a weak negative correlation between the two transducers for these two vocal tasks, in contrast to the significant positive correlation for the two /a/ tasks (R^2 = .257).

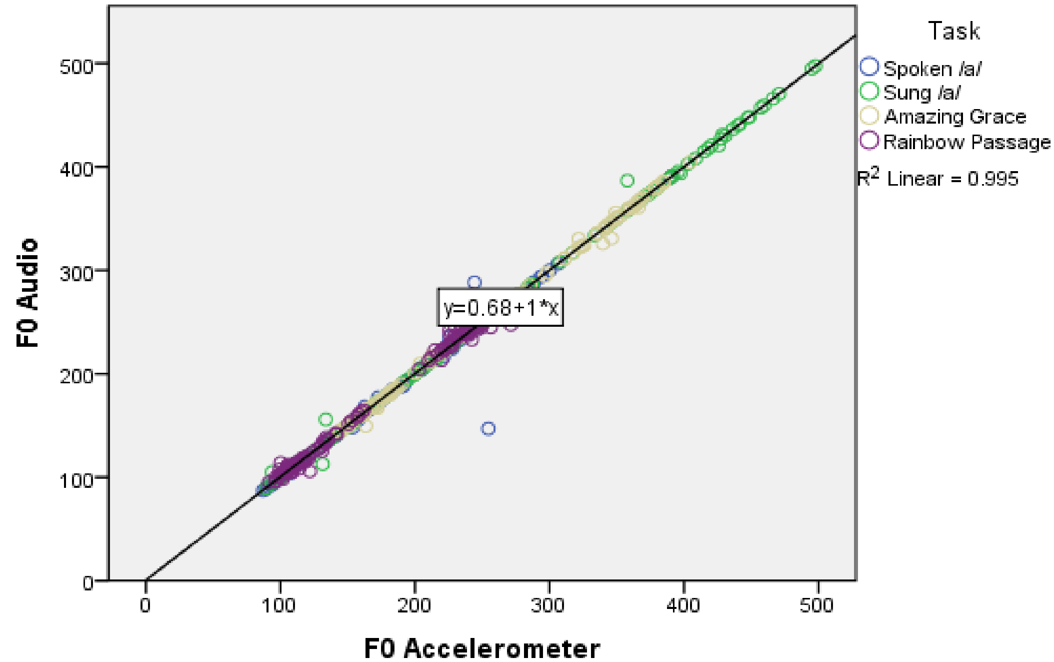

Figure 19. Transducer comparison for mean F_0 readings.

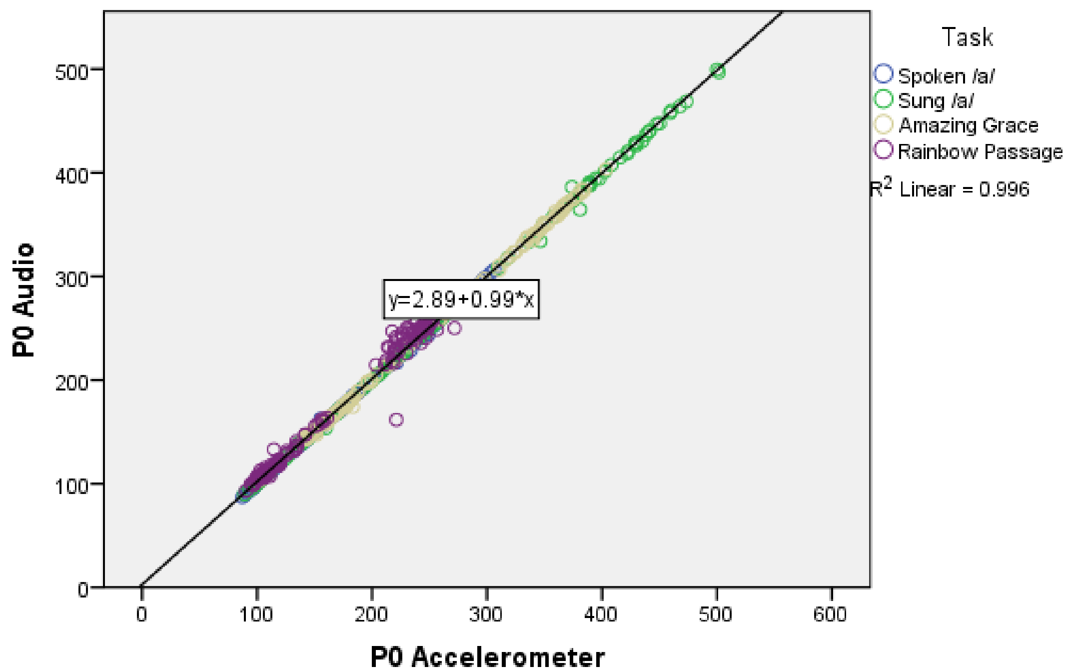

Figure 20. Transducer comparison for mean P_0 readings.

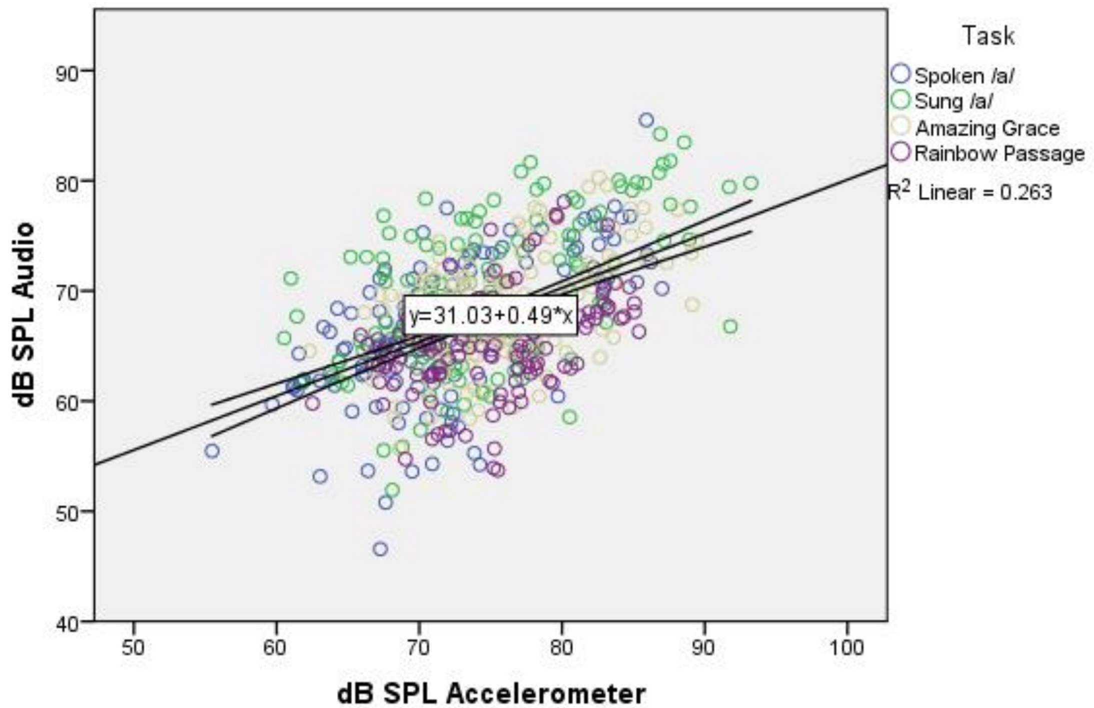

Figure 21. Transducer comparison for mean dB SPL readings.

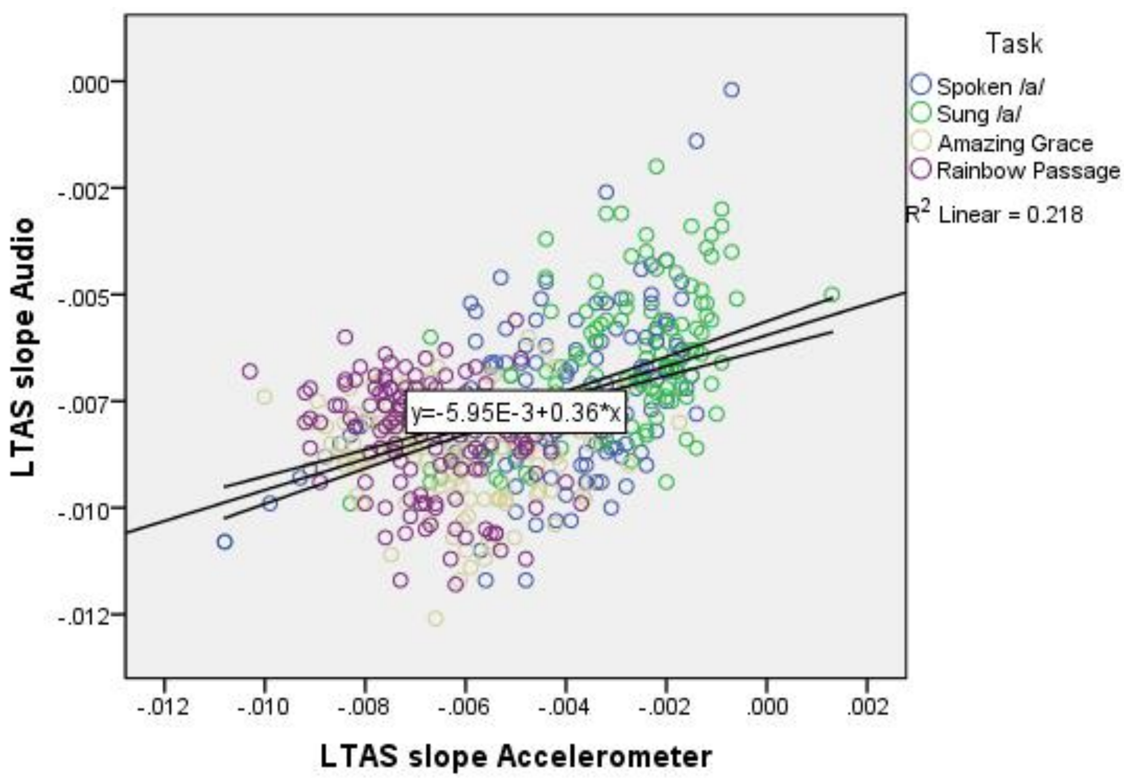

Figure 22. Transducer comparison for mean dB SPL readings.

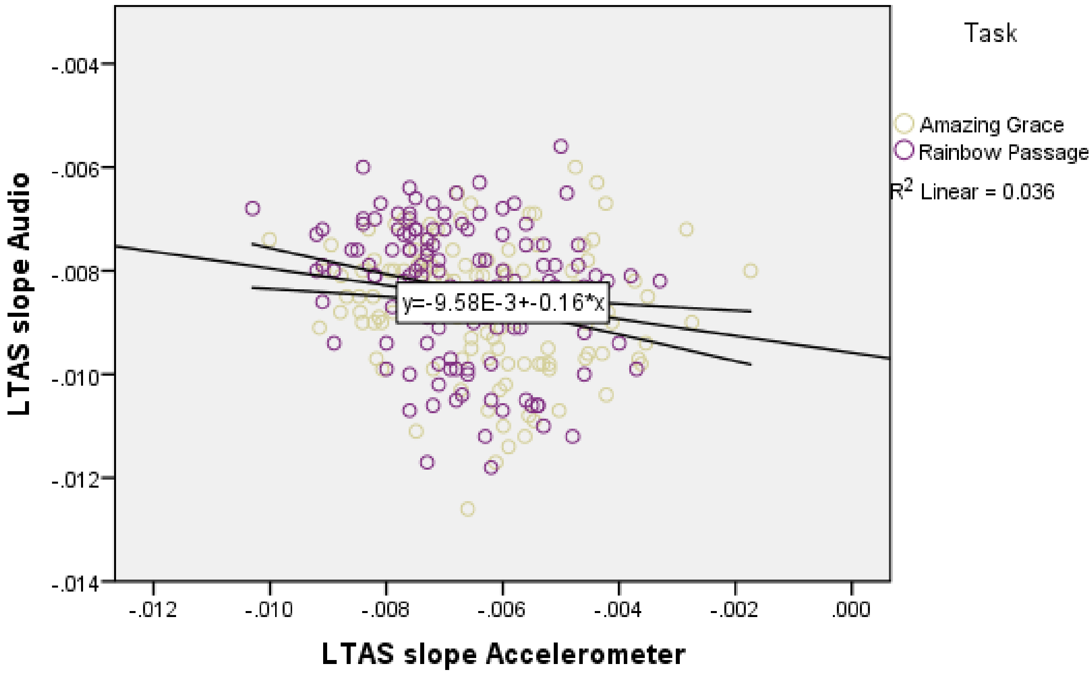

Figure 23. LTAS Slope transducer comparison - Amazing Grace and Rainbow Passage only.

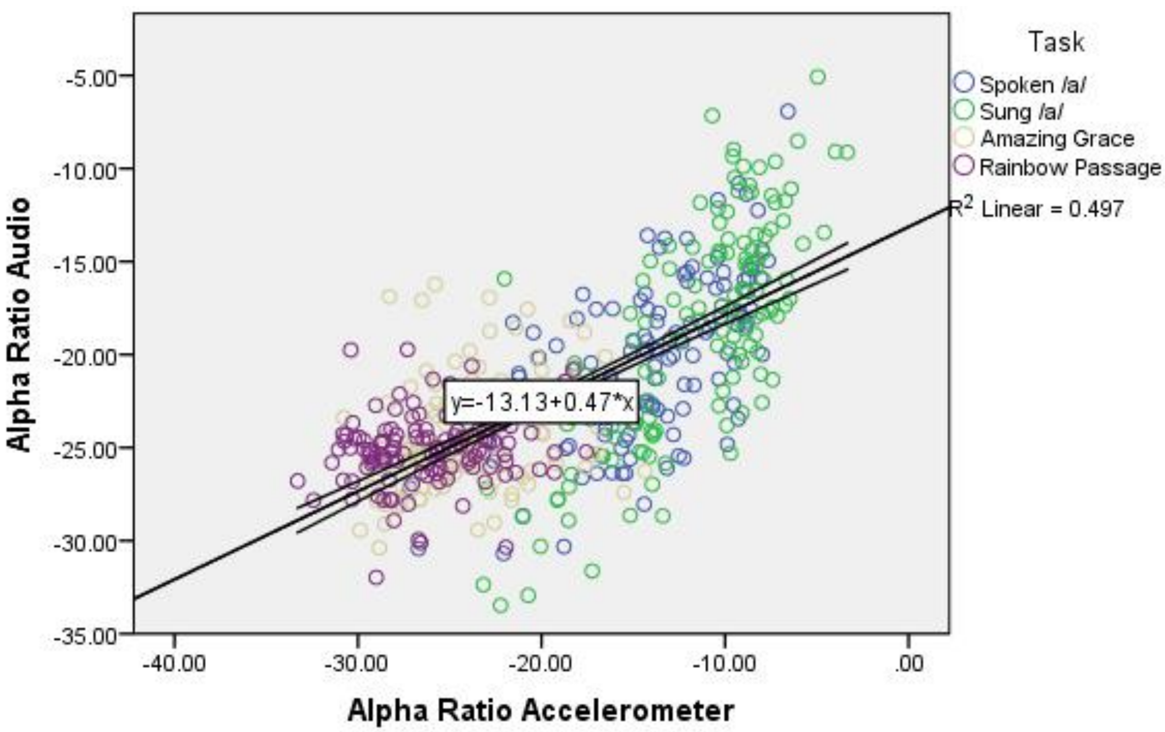

Figure 24. Transducer comparison for mean alpha ratio readings.

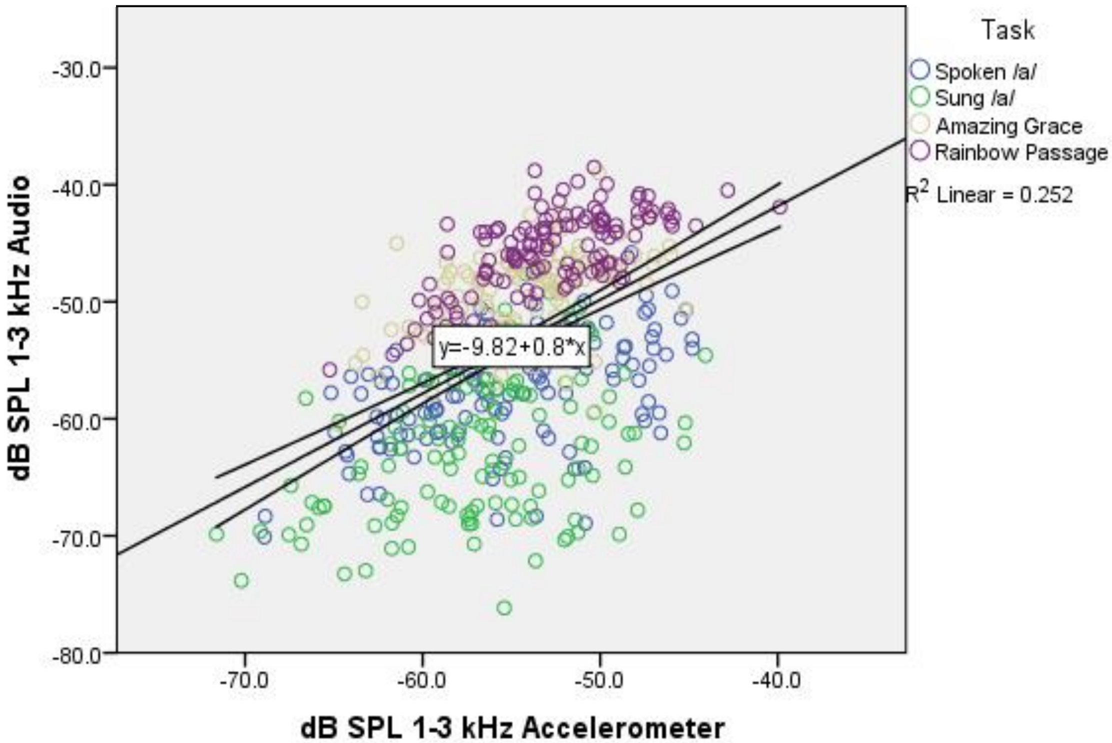

Figure 25. Transducer comparison for mean dB SPL 1-3 kHz readings.

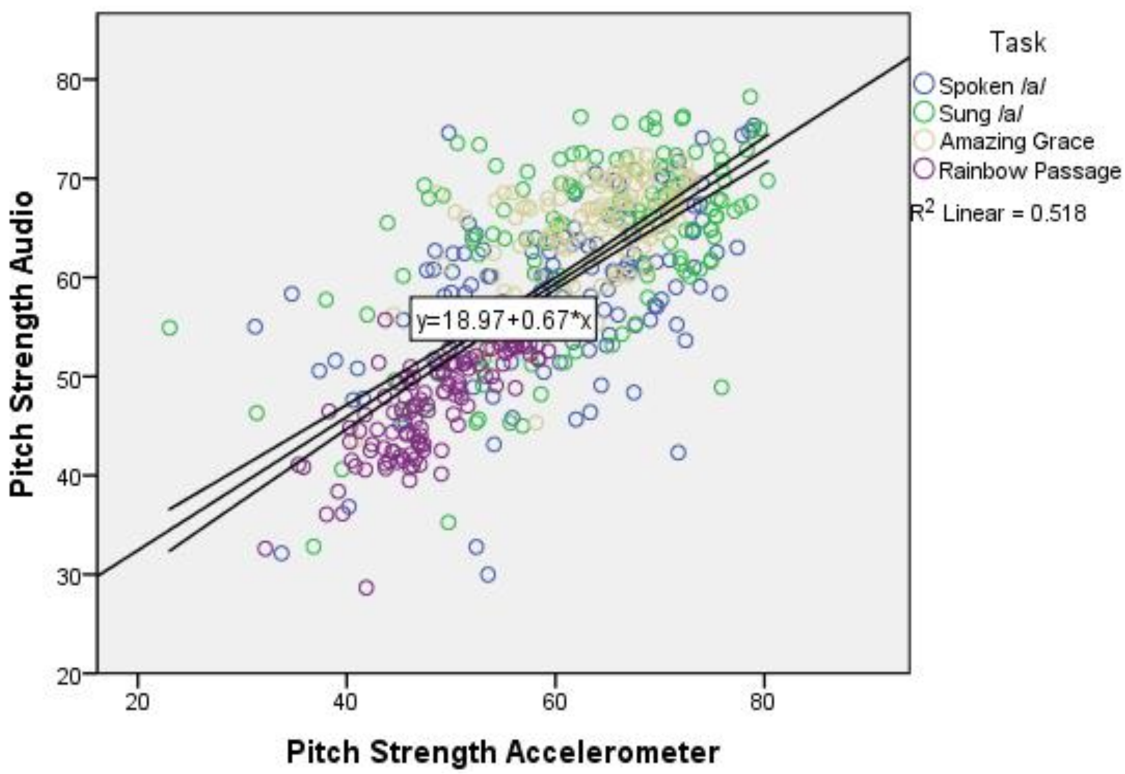

Figure 26. Transducer comparison for mean pitch strength readings.

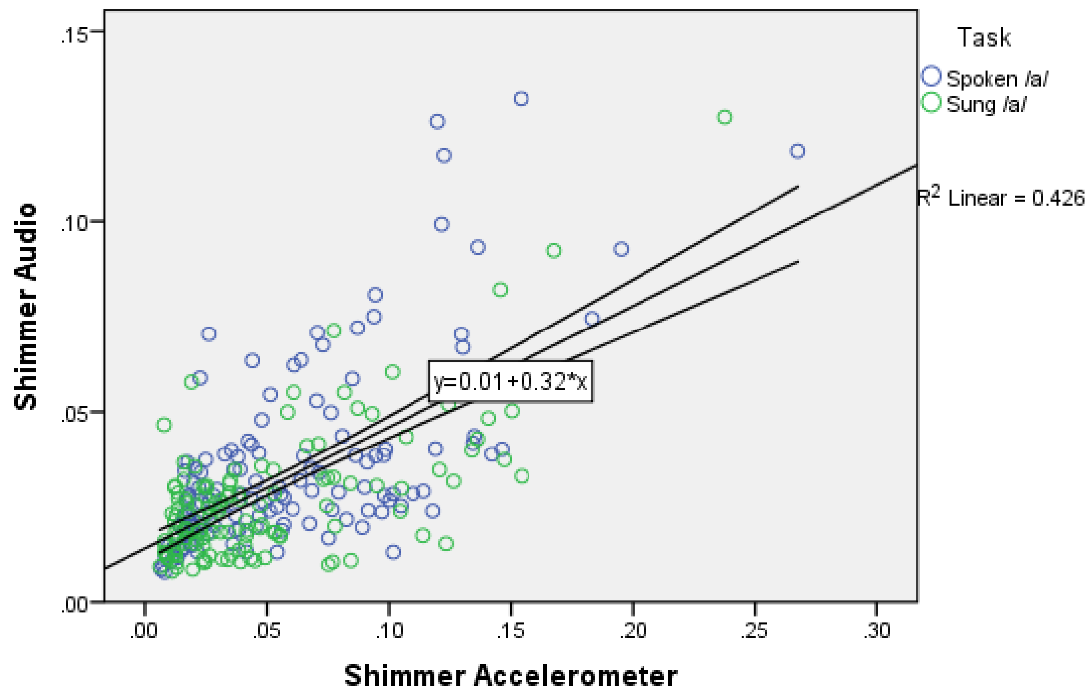

Figure 27. Transducer comparison for mean shimmer readings.

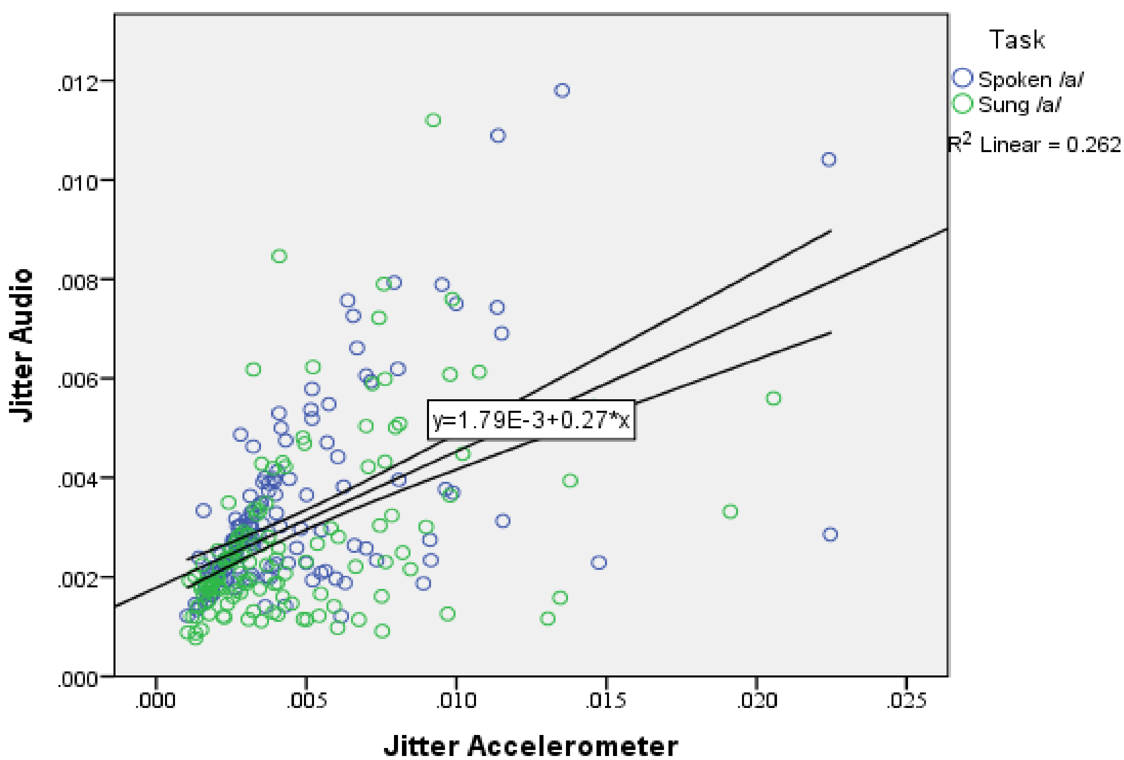

Figure 28. Transducer comparison for mean jitter readings.

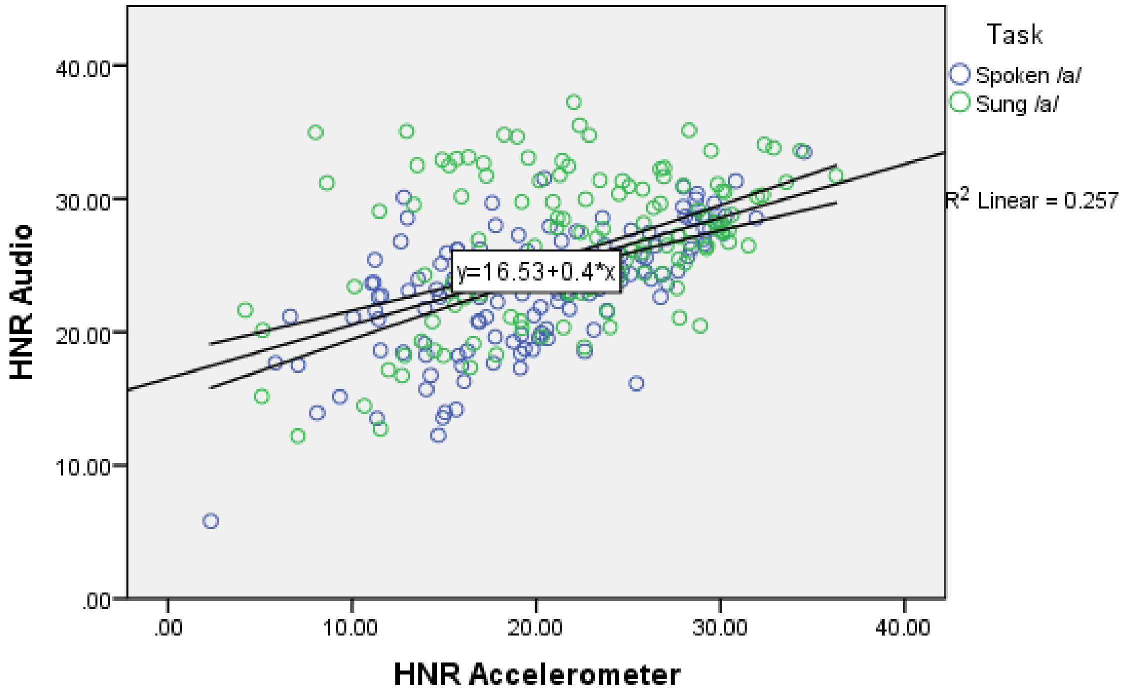

Figure 29. Transducer comparison for mean HNR readings.

Chapter Four: Summary of Findings

Results reported in this chapter indicate numerous statistically significant relationships ($p < .01$). I summarize these relationships below according to (a) dependent measures and (b) major, overarching findings.

Summary by dependent measure. The following is a brief summary of the findings of statistical significance, grouped by measure:

- **Vocal dose measures (Voicing %, Dt, Dc and Dd):** There were multiple significant correlations between daily means of the four dose measures and dB SPL (positive), pitch strength (positive), HNR (positive), shimmer (negative), and jitter (negative).
- **F_0 and P_0 :** By activity, F_0 and P_0 were highest in solo singing. F_0 and P_0 rose from morning to afternoon in three of four vocal tasks and correlated positively with higher EASE scores in three of four vocal tasks. In the two sung vocal tasks, higher pitch

correlated positively with both years of choral experience and years of voice lesson experience.

- **dB SPL:** There were positive correlations between dB SPL and Dt and between dB SPL and voicing percentage when analyzed in terms of individual monitoring days. Men had a higher dB SPL than women during ambulatory monitoring. By activity, dB SPL was highest in solo singing followed by choral singing. dB SPL rose from morning to afternoon in three of four vocal tasks. There was a negative correlation between EASE score and dB SPL in all four tasks, indicating that less ability to sing easily correlated with a lower dB SPL.
- **LTAS slope:** As measured by the accelerometer, LTAS slope was significantly steeper during solo singing than choral singing and significantly steeper in choral singing than in non-singing activities. Students performed their Baseline tasks with an LTAS slope that was less steep than the tasks they completed during the three monitoring days. A higher EASE score correlated with a steeper LTAS slope in the Rainbow Passage.
- **Alpha ratio** increased from morning to afternoon vocal tasks as measured by the audio transducer. Students also performed their Baseline tasks with an alpha ratio that was less steep than the tasks they completed during the three monitoring days. A higher EASE score correlated with a lower alpha ratio in both /a/ tasks.
- **dB SPL 1-3 kHz –** Women had a higher mean in this measure during ambulatory monitoring. There was an increase in dB SPL 1-3 kHz from morning to afternoon in the Amazing Grace tasks.

- **Pitch strength** – There was a positive correlation between pitch strength and voicing %, Dt, and Dd when comparing both the 3-day means for each participant and the daily means for all participants. There were significant positive correlations between total singing Dt and Dd and pitch strength over three days, and a significant positive correlation between non-singing Dd and pitch strength during non-singing periods. Women had a higher pitch strength during ambulatory monitoring. By activity, solo singing had the highest pitch strength, followed by choral singing and then non-singing. A higher EASE score correlated with a lower pitch strength in the spoken /a/ task but a higher pitch strength in the Rainbow Passage task. There were not significant changes throughout the day.
- **Jitter** – There was a negative correlation between jitter and all four measures of vocal dose (voicing %, Dt, Dc and Dd) when comparing the daily means of all participants. There were also significant negative correlations between jitter and the total amount of singing Dt, singing Dc, and singing Dd over three days. By activity, solo singing had the least amount of jitter, followed by choral singing and then non-singing. There were not significant changes in jitter throughout the day.
- **Shimmer** - There were negative correlations between shimmer and voicing %, Dt, and Dd when comparing both the 3-day means for each participant and the daily means for all participants. There were also significant negative correlations between shimmer and total singing Dt and the total duration of singing time over three days.. By activity, solo singing had the least amount of shimmer, followed by choral singing and then non-singing. There were not significant changes in shimmer throughout the day.

- **Harmonic-to-Noise Ratio** – There was a positive correlation between HNR and voicing %, Dt, and Dd when comparing the daily means for all participants. There were significant positive correlations between HNR and both total singing Dc and total singing Dd over three days. By activity, solo singing had the highest HNR, followed by choral singing and then non-singing.

Overarching findings. These individual results can be summarized in five overarching findings:

1. **Higher vocal doses, as a whole, corresponded with greater voice amplitude, more vocal clarity and less perturbation**. There were significant correlations between vocal dose measures and voice amplitude as well as all four voice clarity/voice perturbation measures, with higher doses correlating positively with dB SPL and voice clarity (pitch strength and HNR) and negatively with perturbation (shimmer and jitter). The significant correlations between vocal dose and pitch strength, jitter and shimmer corresponded with significant correlations between the amount of singing time and these measures. There was a significant correlation between Dd and pitch strength when only non-singing time was examined.
2. **There were significant differences in voice quality between different activities** in terms of F_0/P_0, dB SPL and voice clarity/perturbation, with solo singing having the highest pitch, dB SPL, and voice clarity and least perturbation. LTAS slope showed significant decreases between solo singing and choral singing and between choral singing and non-singing activity.
3. **As measured during repeated vocal tasks with the audio transducer, frequency (Hz), dB SPL, and resonance measures increased from morning to afternoon to**

evening. However, there were not changes in voice clarity or perturbation throughout the day as measured by the audio transducer during repeated vocal tasks.

4. **Less perceived ability to sing easily indicated higher pitch frequency and lower voice amplitude as measured by the audio microphone during repeated vocal tasks.** There were multiple significant correlations between mean 4-day EASE scores and mean voice quality readings over four days/ten administrations of the vocal tasks. Pearson correlation tests revealed significant correlations between EASE scores and semitone (positive correlation for 3 of four tasks) and dB SPL (negative correlation for all four tasks). There were some relatively weak significant correlations between EASE scores and other measures that did not agree with one another: pitch strength (a negative correlation for the two spoken tasks), alpha ratio (for positive correlation for the two /a/ tasks), and LTAS slope (a negative correlation for the Rainbow Passage only).
5. **There was close agreement between the two transducers in terms of F_0 and P_0 but significant and irregular differences in between the readings of the other nine measures of voice quality.** There were differences between the accelerometer and audio microphone readings for each of ten measures of voice quality. Linear regression analysis demonstrated that it is possible to predict the mean frequency of an audio signal from an accelerometer signal with a standard error of 3.07% or less of the mean. The other measures showed greater variability between the two transducers, with standard errors of the estimate that ranged from 7.77% of the mean (dB SPL) to more than 51% of the mean (jitter and shimmer).

CHAPTER 5

Discussion

This investigation documents and explores relationships among the voice use, voice quality, and perceived voice function of 19 college/university singing students over the course of three active days during a college/university semester. The instrumentation and procedures of this investigation yield considerable data (see Chapter Four). The major results, however, may be expressed as five overarching findings: (a) significant correlations between accelerometer acquired vocal doses and voice quality data, (b) significant differences in vocal dose and voice quality measures between activities, (c) significant voice quality changes from morning to evening as measured by the audio microphone during repeated vocal tasks, (d) significant correlations between perceived voice function and voice quality as measured by the audio microphone during vocal tasks, and (e) significant and irregular differences between voice quality measures acquired by the two transducers.

The following discussion considers each of these matters in terms of possible meaning, limitations of the study, suggestions for future research, and potential implications for vocal pedagogy. It should be noted that the various vocal dose readings for these young singers (11.92% voicing, 7.15 minutes Dt per hour, 97,320 Dc per hour, and 370.57m Dd per hour) are similar to the dose readings obtained in several earlier studies of student singers (Austin & Hunter, 2009; Gaskill, Cowgill, & Tinter, 2013; Manternach, 2011; Schloneger, 2010, 2011). Readers should bear in mind that all results of this study are limited to its particular participants and are likewise circumscribed by the particular methods, procedures, and measures employed.

Correlations Between Accelerometer Acquired Vocal Dose and Voice Quality Data

The first overarching finding is the presence of significant correlations between vocal dose and voice quality measures as acquired by the accelerometer. Pearson correlation coefficients reveal a considerable number of significant correlations between vocal dose and voice quality measures acquired during ambulatory monitoring, both in terms of total three-day monitoring means (N = 19) and individual monitoring day means (N = 57). These correlations all occur between vocal dose and voice amplitude level or voice perturbation measures.

There are moderate significant positive correlations between dB SPL and both voicing percentage (r = .401) and dose time (r = .406) during individual monitoring days. The correlations are stronger for the three full monitoring day means (Voicing %, r = .493; Dt, r = .512) but are not statistically significant. This circumstance may be due, in part, to the relatively small number of study participants.

When analyzing dB SPL in terms of singing and non-singing periods, results of the correlation tests are quite similar. This similarity may indicate that, for these participants as a whole, the amount of singing time does not particularly influence dB SPL readings. These findings, which show dB SPL levels to rise after periods of vocal loading, are in agreement with previous studies in which the authors suggest that the change is likely due to increased hyper-function of the vocal mechanism (Jonsdottir et al., 2003; Laukkanen et al., 2008; Laukkanen et al., 2004; Vilkman et al., 1999). To see this change in mean dB SPL occur over a full day of vocal loading, however, goes beyond the findings of these earlier laboratory observations and may suggest that individuals might engage in more effortful phonation after periods of higher vocal loading, and as a result the average amplitude level of voicing also increases.

There are also moderately strong, significant positive correlations between vocal dose measures and voice clarity (pitch strength and HNR) and moderately strong, significant negative correlations between vocal dose and perturbation (shimmer and jitter). At first blush, this result seems counterintuitive, as one could expect high vocal doses to result in less vocal clarity and more perturbation. However, there may be at least two plausible explanations for these significant correlations. First, the three-day means of these four measures correlate significantly with the amount of singing time and levels of singing dose. As compared to speaking, singing involves longer periods of time producing vowels and greater attention to breath support and resonance. It follows that more singing time over three days would lead to greater mean readings of voice clarity and less perturbation. There are also significant differences in these measures between different activities (see below for further discussion of differences between activities). Thus, the strength of the correlations may in part be the result of the improved voicing that one would expect with singing.

A second explanation could be that pitch clarity and perturbation measures improve after periods of vocal loading. Though the frequency of singing likely contributes to the strength of the correlations among dose and pitch strength, HNR, shimmer, and jitter, there are also moderate correlations between these measures and the vocal doses acquired during non-singing periods alone. This factor is especially true of Dd, with a significant positive correlation between non-singing Dd and non-singing pitch strength. Amplitude also correlates positively with vocal dose regardless of activity. These results accord with findings of several previous studies (Boucher, 2008; Laukkanen et al., 2008; Rantala & Vilkman, 1999) in which the authors suggest that vocal loading results in vocal hyper-function, and thereby a more firm closing of the vocal folds. This circumstance results in a higher amplitude and increased clarity in voicing.

While the correlations are stronger when compared with singing doses, the fact that the correlations between these voice quality measures and non-singing doses move in the same direction with moderate strength indicates that increased hyper-function could play a part in acoustic voice quality changes. The possibility of increased clarity after a heavy vocal dose exemplifies why it is so difficult, if not impossible, for vocal pedagogues to identify fatigue in a voice from listening alone. If voice quality actually becomes clearer after a period of vocal loading, then there could be no outward indications that would allow even the most experienced and attentive voice teacher to hear a decline in vocal efficiency.

Given these positive correlating changes in voice quality and dose, it is unclear to what extent self-reported healthy singers' vocal efficiency improves after a certain level of voice use (a warming up effect) and at what point vocal efficiency begins to decline. According to Boucher and Ayad (2010), there may be a discernable point after which vocal stability temporarily decreases, followed by a compensatory increase in vocal tension that masks the problem. The analysis methods in this study do not confirm the existence of this point of instability or make clear at what point it might happen, nor do the results make clear what might constitute a warming-up effect on the voice and what might constitute increased compensatory tension due to fatigue. Detailed minute-to-minute analyses of acquired ambulatory monitoring data with this temporary change in mind would be a logical possibility for future research.

It is interesting to note that no significant correlations appear between voice quality means acquired by the tasks and the three day vocal dose means. This fact could indicate that voice quality measures accumulated over hours of ambulatory monitoring with an accelerometer may be better indicators of possible relationships between vocal dose and voice quality than vocal tasks conducted only at certain intervals. On the other hand, this study does not analyze changes from the baseline to final administration of the voice tasks because it was not one of the research questions posed. Acquisition of voice clarity (pitch strength and HNR) and voice perturbation (shimmer and jitter) data from voice source recordings via the accelerometer appears to be a viable way to assess voice quality. Subsequent studies might employ this protocol with a larger group of participants in order to learn more about how voice quality may change over time in a field-based setting.

Significant Differences Between Activities in Vocal Dose and Voice Quality Measures

Ambulatory monitoring data indicate significant differences between the various periods of participant activity assessed in this study. All four vocal dose measures and most voice quality means, including $F_0/P_{0,}$ dB SPL, pitch strength, and HNR, show significant increases between non-singing and both types of singing activities. Shimmer and jitter decrease significantly from non-singing to singing endeavors. Once again, the increase in pitch strength and HNR and corresponding decrease in shimmer and jitter accompany the higher dB SPL and vocal fold closure that typically occur with singing.

Choral singing and solo singing require different vocal techniques, and results of this study indicate differences between the two styles of singing among this group of singers. Pitch strength is significantly higher in solo singing than in choral singing, while jitter and shimmer are significantly lower. Measurements of $F_0/P_{0,}$ dB SPL, and HNR are all higher in solo singing than in choral singing, though not to a significant degree. One would expect these results given the higher demands for projection in solo singing. The greater vocal fold closure needed for projection would logically correspond with a clearer voice and less perturbation.

However, results of the three measures of vocal resonance (LTAS slope, alpha ratio, and dB SPL 1-3 kHz) used to compare participants' non-singing, choral singing, and solo singing time periods in this study appear to contradict some previous findings (Goodwin, 1980; Rossing, Sundberg & Ternström, 1986). On the basis of previous investigations, one would expect to observe increased resonance in singing as opposed to speaking, as well as increased resonance in the upper partials in solo singing when compared to choral singing. For singers participating in this study, however, LTAS slope, alpha ratio, and dB SPL 1-3 kHz each decrease from non-singing to choral singing to solo singing. LTAS slope also decreases from choral singing to solo singing. Subsequent studies should explore this apparent discrepancy to see if it is unique to the participants and procedures in this study or occurs more widely.

One clue may be found in the comparison of the accelerometer and audio tasks data (Research Question Five). For all measures, the data show a significant correlation between the accelerometer and audio readings when all four tasks are analyzed as a whole. However, when the tasks are analyzed individually for LTAS slope, the significant positive correlations occur only with the spoken /a/ and sung /a/ tasks. When the transducer readings are correlated between the more complex voicing of the sung Amazing Grace and spoken Rainbow Passage tasks, there is actually a very weak negative correlation between the accelerometer and audio readings for LTAS slope. This negative correlation may indicate that the accelerometer readings of LTAS slope between the different activities could be much different, perhaps even reversed, when the readings are acquired by an audio microphone. The lack of a consistently strong correlation between the two transducers also limits the possibility of accurately predicting the equivalent audio reading through statistical regression. The ability of an accelerometer transducer, which measures vocal source vibrations, to accurately and reliably measure vocal resonance is certainly a question that warrants further research.

Significant Voice Quality Changes From Morning to Evening

Although repeated measures analyses of participant vocal tasks show few changes from day to day in this study, these multiple analyses do indicate significant changes in vocal task readings between morning, afternoon, and evening. Almost all measures show increases between morning and afternoon, then remain level or perhaps decline slightly toward the morning mean between afternoon and evening. Most significant changes occur between morning and afternoon periods.

Data show significant increases in F_0 in all four vocal tasks and significant increases in P_0 and dB SPL in three of four vocal tasks. As is the case with the ambulatory monitoring results, these findings agree with a considerable body of previous research (e.g., Artkoski et al., 2002, Jonsdottir et al., 2003; Laukkanen et al., 2004; Vilkman et al., 1999) that finds increased F_0 and dB SPL throughout the day among persons with normal, healthy voices. Likewise, there are significant increases in some of the spectral measures during the two singing tasks throughout the day: (a) significant increases in alpha ratio in the sung /a/ and Amazing Grace tasks, and (b) a significant increase in dB SPL 1-3 kHz during the Amazing Grace task. Because singers tend to increase their resonance energy when singing as compared to speaking, a larger change across the day makes sense and may correspond with more engaged musculature throughout the day.

Because the largest changes occur between morning and afternoon, one could speculate that these daily changes have more to do with the vocal instrument stretching and warming up than with negative changes from excess vocal dose. However, the present study does not make entirely clear which changes occur as a result of improved vocal function and which changes might be a result of overuse and hyperfunction. I would venture that these changes may reflect what many singers, teachers, and students of singing already know anecdotally, i.e., the body and voice need time to wake up and warm up early in the day, and they often function most efficiently later in the day. Vocal pedagogues and choir directors might keep this possibility in mind when scheduling lesson and rehearsals, and if an early morning session is necessary, increase warm-up time accordingly.

Significant Correlations Between Perceived Voice Function and Voice Quality As Measured By The Audio Microphone During Vocal Tasks

While this study finds no significant correlations between mean 4-day EASE scores and accelerometer acquired full-day data among its participants, there are some significant correlations, both positive and negative, between mean 4-day EASE scores and some voice quality measures acquired from the vocal tasks with the audio transducer. The positive correlation between EASE scores and semitone, indicating that the students tend to vocalize at a higher pitch as their ability to sing easily decreases, could relate to observed positive correlations between frequency and dose and significant increases in pitch throughout the day. That is, less ability to sing easily could possibly coincide with greater laryngeal muscle tension, thereby increasing the mean pitch of the voice.

It should be noted that moderate positive correlations also occur between mean 4-day EASE scores and the two measures of voice frequency as acquired during ambulatory monitoring with the accelerometer, F_0, $r = .381$ and P_0, $r = .343$. While these correlations are not statistically significant, the fact that there are similar moderate positive correlations for both data acquisition methods may indicate a connection between perceived ability to sing easily and pitch. Subsequent research is needed to confirm or deny this possibility.

The significant negative correlation between EASE scores and dB SPL during voice tasks indicates that decreasing ability to sing easily may coincide with decreasing voice amplitude.

This result differs from the vocal dose results that show increasing amplitude correlating with vocal dose. However, given no significant correlations between EASE scores and vocal dose, higher doses do not necessarily indicate a perceived decrease in ability to sing easily.

One could speculate that because students likely think actively about their vocal production while completing the vocal tasks, they would be more careful with their voices and vocalize at a reduced amplitude (i.e., sing softer) while completing the tasks. Another factor contributing to this result could be the differences between this particular group of men and women. Male participants in this study have a higher mean dB SPL than women, and women have a higher mean EASE score than men *(p* = .028).

It is interesting that EASE scores correlate significantly with some voice quality readings from the tasks but not from the full days, while vocal dose readings correlate significantly with some voice quality readings from the full days but not from the tasks. The results of this study appear to suggest real interactions occurring between vocal dose, voice quality, and perceived singing voice function, but the study results do not make completely clear the specific ways in which dose, voice quality, and perceived function interact. More research with a larger *N* is needed in order to clarify understanding of these relationships.

Significant and Irregular Differences Between Voice Quality Measures Acquired By The Two Transducers.

The results from Research Question Five show a consistently close agreement between the two accelerometers in terms of F_0 and P_0, demonstrating that one can predict acoustic frequency from bio-acoustic accelerometer data. The standard error of the estimate is within 5.46-6.58 Hz of the mean reading, a negligible difference in terms of pitch as perceived by the human ear.

In terms of the remaining measures (dB SPL, LTAS slope, alpha ratio, dB SPL 1-3 kHz, pitch strength, jitter, shimmer, and HNR), the results are inconclusive and therefore warrant further study. The results show large standard errors of the estimate for each of these variables in the prediction of acoustic readings from the accelerometer readings. When the standard error of the estimate is calculated as a percentage of the mean audio reading for all task repetitions, dB SPL shows the smallest percentage error of the estimate out of all eight variables (5.25 dB SPL is 7.77% of the mean audio reading for dB SPL). When one considers that dB SPL is a logarithmic scale and a 3 dB SPL increase indicates a doubling of sound pressure it becomes evident that the difference may be too large to directly compare data acquired from the accelerometer with the audio data. This standard error is greater than the estimate of accuracy within ±2.8 dB (95% confidence interval) found by Švec, Titze and Popolo (2004). Future studies might investigate such differences between the transducers.

The three spectral measures (LTAS slope, alpha ratio, and dB SPL 1-3 kHz) all have a standard error of the estimate between 13.07% and 19.74% of the mean reading. The differences in one of the measures, LTAS slope, are even greater in the two more complex vocal tasks, Amazing Grace and the Rainbow passage. When the transducer readings for these two tasks are correlated, there is a negative slope compared to a positive slope for the /a/ tasks. These results call into question the ability of the accelerometer to predict audio readings of spectral sound. This irregular difference may not come as a complete surprise, because the accelerometer captures primarily vocal source sounds, and the spectral energy captured by the audio microphone represents the source/filter interaction of the vocal source and vocal tract. An audio reading takes into account the resonance characteristics of the participant's vocal tract. Because these resonance characteristics may vary somewhat between individuals, it follows that there might not be strong relationships between the vocal source reading of the accelerometer and the vocal resonance reading of the audio microphone.

Another explanation for the differences between the two transducers in terms of the three spectral measures (LTAS slope, dB SPL 1-3 kHz, and alpha ratio) may be the more limited sensitivity of the accelerometer to higher frequencies. It is well established that the declination rate of the spectral slope is largely dependent on the strength of vibrations from the vocal source, perhaps even more so than on vocal resonance characteristics (Leino, 2009; Titze, 2000). Based on this information, one might expect stronger correlations between these three spectral measures, and a strong correlation might be the finding if both transducers measured high frequencies more easily. However, the Knowles accelerometer included in the VoxLog collar begins to display less sensitivity relative to dB above 2.5 kHz. Thus, all three measures would lose strength in the upper harmonics when measured by the accelerometer as compared to the audio transducer. LTAS slope in particular, because it includes the highest frequencies, would be most affected by this difference in transducer sensitivity. Because room acoustics do not influence the accelerometer, it would be more sensitive to an early roll off of the glottal source frequencies.

The acoustic microphone, on the other hand, would be more influenced by the vocal resonance manifested at higher frequencies. These differences in high frequency readings would explain why there would be weak or even negative correlations betweent the two transducers in LTAS slope. Because the range of most singing incorporates higher frequencies than spoken or sung /a/ vowels, it makes sense that there is not a significant relationship between the LTAS readings for the sung Amazing Grace task. The differences in high frequencies would also explain why the relationships are stronger for dB SPL 1-3 kHz and alpha ratio, which measure only lower frequency bands, than for LTAS slope.

The difference between glottal source and resonance frequencies measured by the two transducers may also partially explain why the accelerometer readings that show a significantly steeper LTAS slope for solo singing as compared to choral singing and significantly greater spectral energy for non-singing periods as opposed to solo singing in all three spectral measures (LTAS slope, alpha ratio and dB SPL 1-3 kHz). It is well established that solo singing typically results in more intense glottal closure than choral singing and speaking (Goodwin, 1980; D. G. Miller, 2008; Rossing, Sundberg & Ternstöm, 1986). Thus, the negative correlation between the transducers might partially explain these unexpected results. Whether these readings are a function of the speaking and singing techniques of this particular group of students, represent characteristics of this particular age group, or represent how the acceleromter transducer aquires these data is an area that requires further study.

Linear regression analyses of the four remaining measures of voice clarity and perturbation all evidence standard error of the estimates greater than 11% of that measure's mean reading. Pitch strength shows the strongest correlation between the two transducers, which with a 99.47% agreement among the mean readings of all tasks. According to a paired *t*-test, the difference between the mean readings of pitch strength between the two transducers is not significantly different. While the mean readings show close agreement overall, there is, however, a significant difference between the standard deviations of the readings, $t = -4.69$, $p < .001$. As a result, the data reveal a standard error of the estimated audio reading of 6.89%, an error amounting to 11.74% of the mean reading. Once again, the size of the estimated error would make it difficult to predict an audio reading with confidence.

The remaining three variables, shimmer, jitter, and harmonic-to-noise ratio, are calculated only for the two /a/ tasks in this study. Even with pure vowels, these measures show significant differences between the mean readings of the two transducers. The standard error of the estimated audio reading from the accelerometer amounts to 18.48% of the mean for HNR and greater than 50% of the mean for shimmer and jitter.

These results indicate that it may not be possible to compare directly the results of most voice quality measures acquired by an accelerometer transducer with simultaneously acquired results from an audio transducer. It may also not be possible to accurately predict the value of an audio reading from an accelerometer reading using simple, univariate linear regression. If it is not possible to accurately predict readings from one transducer type to another, then individualized studies of each analyzed variable, in order to establish new bioacoustic baselines, would be helpful. If such prediction is possible, more complex statistical models that take into account the influence of multiple variables might be needed. Such models, however, are beyond the scope of this study and could be the focus of future studies, particularly in terms of spectral data. A recent study by Ghassemi et al. (2014), for example, demonstrates a potential further direction in this area. This study employs a full accelerometer signal and a complex statistical regression model to correctly identify the presence of vocal nodules. Further development of such models would allow pedagogues and clinicians to complete additional and more accurate analysis of students' and clients' voices before referral to a physician and an accompanying laryngoscopy.

Relationships Between Significant Correlations and Transducers

The three spectral measures analyzed in this study, LTAS slope, alpha ratio, and dB SPL 1-3 kHz, do not demonstrate significant correlations with vocal dose data acquired by the accelerometer transducer. In fact, they demonstrate some results that are, according to the literature, the opposite of the expectation among different activities. However, some or all of these measures do show differences over time in the vocal tasks acquired by the acoustic microphone (morning to evening and baseline to final administration). This difference between transducer readings might indicate that the acoustic microphone gathered more accurate readings than the accelerometer in terms of these three spectral variables, or that something beyond voice source characteristics changed to alter the spectral characteristics of the sound throughout the day. Explorations of the possible relationships between the voice source, filter, and transducer types presents an avenue for further study.

In direct contrast to the three spectral measures, the four voice quality measures of voice clarity and perturbation show more significant differences when acquired with the accelerometer than with the audio transducer. Pitch strength, shimmer, jitter, and HNR all correlate significantly with vocal dose measures as acquired with the accelerometer. Of the four measures, however, only pitch strength correlates significantly with changes in repeated vocal tasks acquired over time with the audio transducer. These four measures, particularly and jitter, are largely measures of the quality of sound produced at the vocal source. As such, they might be more accurately measured by an accelerometer transducer, especially in an ambulatory setting. Of interest is the fact that all four measure correlate significantly with vocal dose, a finding that (a) agrees with previous research on the effects of vocal loading (e.g., Boucher, 2008; Laukkanen et al., 2008; Rantala, & Vilkman, 1999), and (b) indicates that such measures may be useful in the analysis of ambulatory voice monitoring.

In sum, results from these transducer comparisons suggest that the VoxLog collar's two transducers and a study protocol incorporating a combination of ambulatory monitoring and vocal tasks could provide a more complete picture of changes in voice efficiency over time, with the acoustic transducer used to analyze spectral characteristics of the voice as acquired during vocal tasks and the accelerometer transducer used to analyze vocal dose, F_0, voice clarity, and perturbation.

Limitations of the Study

This study employs a new method of voice dosimetry. Consequently, a number of its protocols and analysis methods had limited prior testing. Also, the study required a three-day commitment from each participant during which time participants needed to complete multiple tasks in accordance with study protocols without the researcher present. As a result, there are a number of limitations to the results of this study. Here follows a forthright acknowledgement and description of these limitations, so that future studies may benefit from considering and addressing them.

Number of participants. Some of the 19 participants did not comply fully with study protocols. Some removed the collar for short periods during the day for reasons both acceptable and unacceptable according to study protocols (for a reported average of 31 minutes each monitoring day). Because these participants reported waking minutes not recorded during some monitoring days, daily changes in voice quality could not be consistently compared to 100% of each participant's daily vocal dose.

Compliance with the protocols for the four vocal tasks was the most problematic aspect of this study for student participants. These college and university students had hectic, uneven schedules, a factor that complicated their ability to record the vocal tasks during requested time frames. Some participants, for instance, reported difficulty in finding a quiet place to record the vocal tasks. Other participants could not complete the morning task before noon, because they did not get out of bed until after the noon hour.

Some students simply forgot to record the vocal tasks. Upon noticing compliance problems with the first dozen participants, I began texting each participant three times during each monitoring day at the beginning of the requested tasks completion period. This strategy greatly improved tasks compliance with the remaining participants. However, my failure to realize this necessity sooner contributed to a reduction of useable, vocal task data sets.

Occasional technical difficulties. Overall, the VoxLog collars and Roland R-05 recorders performed well. There were occasional technical difficulties with recorders. Most resulted from user error. For example, a student forgot to turn on the Roland's "hold" button once recording had started so that the recorder would not turn off when bumped. Another forgot to change the SD card for the second or third day so that the card eventually exceed recording capacity. In one case, the AA batteries powering the Roland recorder ran out of power late in the day, cutting off the last hour or so of monitoring. I had to eliminate one student from the study because the VoxLog collar cord connecting the collar to the digital recorder failed, likely due to a short in the cord. This failure occurred after the collar had been used to acquire more than 400 hours of data.

Contamination of ambient periodic sound in accelerometer data. Contamination of accelerometer data by ambient periodic sound proved to be an unexpected and difficult challenge. The accelerometer transducer measured skin vibrations in the neck, and in doing so it picked up low level vibrations of ambient sound. These sounds were initially inaudible, but the accelerometer signal needed to be amplified by 25-30 dB SPL in order for analysis to take place. This amplification often made ambient sound audible in the recorded accelerometer file.

The PRAAT and Audswipe algorithms sometimes misinterpreted periodic ambient sound, such as the sounds of other voices or musical instruments, as participant voicing. In most cases, the lowest recorded intensity level of the vocal source sounds was greater than the loudest intensity level of the ambient periodic sound, so the problem was largely corrected by identifying a lower dB threshold for each individual through observation of different sections of recorded sound and employing a high pass filter on the data which eliminated all data below that intensity level (Figure 30). There were cases, as figure 30 also demonstrates, in which the loudest ambient periodic sounds overlapped with the lowest intensity levels of subject voicing, particularly in terms of musical instruments.

I took two additional steps to eliminate false readings remaining after the high pass filtering was completed. In addition to a high pass filter, all minutes in which instruments were played by the participants were removed and all full minutes below a second individualized dB SPL threshold were also removed. One can see that the histogram in Figure 30 was still not entirely normal after the high pass filter was applied. These two additional steps applied after the point displayed in Figure 30 helped to eliminate additional false voicing readings and further normalize the curve.

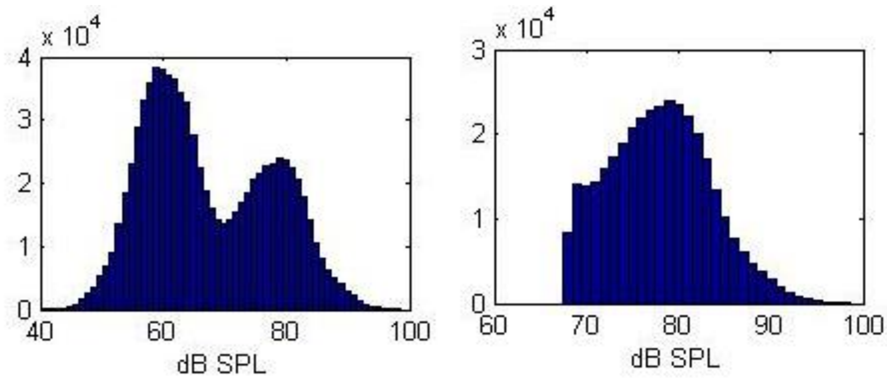

Figure 30. dB SPL histogram of a participant with multiple hours of instrument playing over a full day before and after high pass dB SPL filter.

I made an effort made in the final analysis to choose the lower dB SPL threshold levels conservatively in order to minimize the influence of false voicing data on voice quality measures. This maneuver likely resulted in the clipping of some lower intensity voicing data from some participants. The final protocols and individualized dB thresholds were the result of months of repeated trials and errors on multiple days of monitoring by multiple participants. These factors may have slightly lowered the overall vocal dose readings and influenced some of the other readings.

At the same time, it is likely that a small amount of false positive voicing readings remained in the final analysis. The fact that dB SPL thresholds needed to be calculated individually likely contributed small differences in data accuracy between individuals. Comparisons with the KayPentax APM in the pilot study indicate that any final false voicing rate is at worst similar to the error rate in that device. Nonetheless, the inability of the accelerometer to completely eliminate ambient periodic sound constitutes a limitation of this study.

However, one advantage of recording with the full accelerometer signal as opposed to the data sampling method of the KayPentax APM and other earlier voice dosimeters is that one can listen to the original recording to determine if voicing readings are accurate. In this study, comparisons of short sections of recorded sounds reveal false voicing readings as well as instances of voicing not interpreted as such by the algorithms. Future studies should investigate if it is possible to eliminate these false readings in accelerometer data, perhaps through improved algorithms that can either eliminate non-human periodic sounds or identify the participant's voice. Subsequent studies may also consider better insulation of the VoxLog collar's accelerometer to see if that procedure eliminates more ambient sound.

Limitations of pitch extraction algorithms. Figure 31 demonstrates a one-minute window of vocal tasks phonation by a female participant, beginning with the Amazing Grace task and ending with the beginning of the Rainbow Passage task. The middle window shows the F_0 readings by both PRAAT (red) and Audswipe (blue). One can see the general agreement between the algorithms for both the speaking and singing tasks, but some different outlier readings as well.

These differences appear in both the audio transducer and accelerometer data and demonstrate the imperfection of both algorithms in correctly identifying voicing, both in terms of false voicing readings and missing actual voicing. Researchers have been developing different pitch extraction algorithms for decades and analyzing their effectiveness (Bagshaw, Hiller & Jack, 1993; Camacho, 2012; Camacho & Harris, 2008; Qiu, Yang & Ko, 2004; Sun, 2000; Rabiner, Cheng, Rosenberg & McGonegal, 1976). Though there are differences, these two algorithms appear to be two of the best according to previous research (Camacho, 2012; Camacho & Harris, 2008; Cheveigne, 2002). It is hoped that the use of both algorithms, including the averaging of the two for ambulatory monitoring data, provides a more accurate picture of overall voice use.

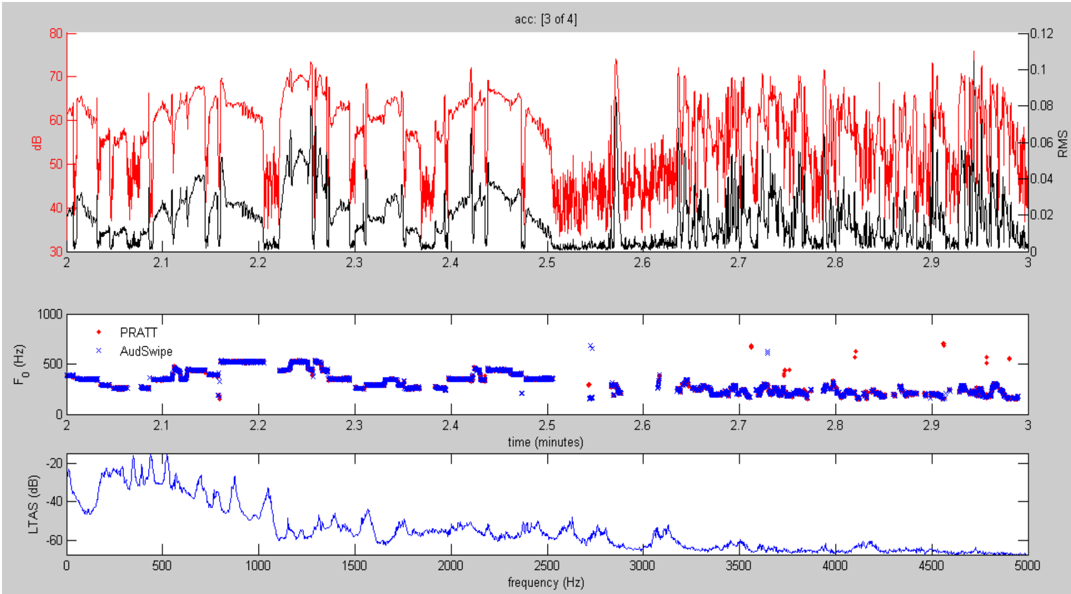

Figure 31. One-Minute MATLAB output for vocal tasks

Potential Benefits, Challenges and Suggestions for Future Research

Potential benefits. Despite the above limitations, this field based, ambulatory study identifies among its dependent variables a considerable number of significant relationships that appear to agree with previous studies conducted in laboratories. This factor could indicate that the protocols and procedures of this study, while imperfect, are sufficiently robust to accurately identify trends in vocal dose and changes in voice quality. These protocols and procedures can continue to be refined as an alternative to purchasing commercial equipment and software costing multiple thousands of dollars.

Unlike earlier dosimeters, which collected only limited samples and discarded the majority of collected data, this dosimetry method retains the full signal. With the full signal, one can go back and confirm the presence of voicing at any moment. Continued experimentation with different analysis methods is also possible. The current approach would allow for calculations of additional measures (e.g., COMMA CPP based, Mel CC, HFCC, dHFCC, HFCC

SDS, glottal flow, etc.) and the signal can always be re-processed as new measures present themselves.

Challenges. While the long-term benefits of this new method of dosimetry could be of immense value to the field, the method as described requires considerable expertise, preparation, and computer processing time. These factors make the time cost of analysis a significant hurdle. Issues of data storage management, the need to listen to multiple sections of the recording to determine lower dB SPL thresholds for each individual (so that ambient periodic sounds are not included), and the current necessity to cut and paste data among spreadsheets are all elements that make this method extraordinarily time consuming and increase the possibility for error.

There is also a learning curve for the data processing software tools. Add to this learning curve the fact that MATLAB processing time may be as slow as one-minute of processing per one-minute of recorded time if the personal computer is not exceptionally powerful, and the cost/benefit ratio of this method changes a great deal. The development of some data processing automations will likely be required if this method is to be widely adopted. Improvements in processing time and the development of commercialized software that automates the majority of the process will also likely be necessary before voice dosimetry becomes widely utilized by pedagogues and clinicians.

Data storage is also an obstacle. A recording period of 100-minutes consumes about one gigabyte of storage at a 44.1 kHz sampling rate. If one wishes to save the original data set for later reference or further analysis, additional gigabytes are required for storing processed data. The approximately 1000 hours of data recorded for this study consumed nearly a terabyte of data storage and a second terabyte of cloud storage to back-up the information. The fact that large amounts of secure cloud storage are now readily available is an advantage, but the time and expense needed to manage files of these sizes is still considerable.

Privacy is another potential challenge for future studies that employ collars with an audio microphone. While most states allow for single consent (non-targeted) recording, including the state where this study was conducted, privacy, HIPPA, and recruitment can be issues that complicate full measurement of all phonation. After the amplification and normalization of the accelerometer signal, the speech of the participant and at times other individuals nearby is sometimes intelligible even when listening to the accelerometer signal alone. Behavioral studies have long allowed the recording of study participants with consent, but if full recordings of the Vox Log's two transducers are to move into the realm of healthcare where HIPPA becomes an issue, then patient privacy becomes a much more significant concern and limitation. Researchers will need to carefully design any future studies to address such privacy issues.

Further suggestions for future research. This investigation is the first to employ the VoxLog collar with a standard off-the-shelf digital recorder and, as such, is (a) the first study to explore a potentially budget friendly method of ambulatory monitoring using an unfiltered accelerometer signal and (b) one of the first studies to employ a device that enables simultaneous ambulatory recording of accelerometer and audio signals. The development of an analysis protocol for this budget method also resulted in several other "firsts":

- This is the first study to explore the voice quality measures of perceived pitch, pitch strength, shimmer, jitter, and harmonic-to-noise ratio acquired from a full accelerometer signal in a non-laboratory, ambulatory setting
- This is first study to directly compare the PRAAT and Audswipe algorithms in the extraction of F_0.

- This is the first study to do a direct statistical comparison between simultaneously acquired accelerometer and ambulatory signal data.
- In the preliminary study, this is the first comparison of vocal dosage data simultaneously acquired by the KayPentax APM and the VoxLog collar.

While these new approaches grew out of a need to develop an effective analysis protocol, they each resulted in an initial data set that offers new insight into the effects of voice use or the comparative effectiveness of different analysis methods. Each of these new approaches would benefit from individually focused future studies.

Questions remain as well about the relationship of audio data to the bioacoustic data acquired by the accelerometer, particularly in terms of spectral measures such as LTAS and alpha ratio. If it proves impossible to predict equivalent audio/acoustic readings from accelerometer data, then different standards and baselines will need to be established for these measures.

Implications for Vocal Pedagogy

The results of this study offer several implications for vocal pedagogues. These implications will be discussed in two general categories: (a) implications for voice dosimetry in the studio or clinic and (b) implications for managing student voice use.

Voice dosimetry in the studio or clinic. This study employs protocols developed for the collection and analysis of ambulatory monitoring voice data using inexpensive and accessible equipment. While numerous questions for future research and development remain, outcomes of this study suggest that the basic method can be successful. The accuracy of the vocal dose information collected at worst rivals that of commercially produced ambulatory phonation dosimeters. And, of course, the simultaneous acquisition of vocal dose and voice quality data modeled by this study affords researchers and practitioners alike more comprehensive data than traditional phonation dosimeters. Overall, results of the voice quality analyses used in this study indicate general agreement with the published literature on voice changes resulting from vocal loading, another factor that bodes well for the future of this approach.

With further refinement and eventually computerized automation of some of the protocols, voice professionals could use this inexpensive instrumentation and analysis method most anywhere, including private studio and clinic settings. Acquired data could be used by a voice teacher who wants to explore why a student seems consistently vocally fatigued or by a clinician who wants to observe how well an injured patient complies with protocols designed to improve voice efficiency and quality. Ambulatory monitors are currently used for a variety of reasons in the medical community, from analyzing heart function to acidity level of the throat through a pH monitor. An ambulatory voice monitor used for the waking hours of each day that the pedagogue or clinician is not with the student might reveal particular voicing habits and behaviors that could contribute to vocal problems..

Managing student voice use. The results of this study provide evidence for possible connections between vocal dose and changes in voice quality over time. Results of the analyses on full-day accelerometer data agree with results from previous studies (e.g., Boucher, 2008; Laukkanen et al., 2008; Rantala, & Vilkman, 1999) that link vocal loading with increased laryngeal tension. This increased tension may be inaudible to even a trained pedagogue because the tension results, at least in the short term, in increased rather than decreased voice clarity. Even this study's analysis of audio recordings of repeated vocal tasks does not reveal significant connections between vocal dose and changes in pitch strength, HNR, jitter, and shimmer over time. These changes are only revealed in analysis of the voice source data provided by the accelerometer over hours of ambulatory monitoring.

Such matters suggest a need for increased awareness by voice pedagogues (voice teachers, choral directors, opera and musical directors) in a college/university setting of the broader demands on their students' voice use. This awareness might prompt voice teachers and choral directors to limit rehearsal time accordingly, without relying on audible changes to know when enough is enough. Pedagogues can also facilitate students' understanding that the same larynx is used for singing and speaking and assist students to plan their use of time outside of rehearsal in terms of potential vocal demands.

A specific example of high vocal dose levels from this study illuminates this need. One participant, a twenty-three year old male voice performance major, had extremely high vocal dose levels during the first two days of the study, with voicing percentages of 18.02% and 23.13% respectively. Over these two days, he participated in 150 minutes of collegiate choral rehearsal, 105 minutes of rehearsal of a student-organized barbershop quartet, a 60-minute voice lesson, and 53 minutes of voice practice, for a total of six hours and eight minutes of singing. He also held a student job as an assistant to an institutional outdoor sports team and had 179 minutes Dt during non-singing hours. In 29.78 hours of recording over these two days, this student evidenced 6.15 hours of phonation time, more 4.83 million vibratory cycles, and a distance dose of 26.90 kilometers. The student presented a baseline EASE score of 33 (the mean score overall was 33.94). While the score actually decreased to 26 at the end of the first day of monitoring, he recorded a score of 46 at the end of the second day.

This student had a much lighter day on the third day of monitoring, with 8.99% voicing, and his EASE score returned to the baseline score of 33 at the end of the third day. However, there were changes in voicing that manifested themselves on the third day. The student's full day shimmer, jitter, and HNR readings during non-singing hours, as measured by the accelerometer, changed each day. (I used non-singing hours for direct comparison because each day had a different amount of singing.) Jitter decreased from 2.99% on Day 1 to 2.83% on Day 2 but increased to 3.13% on Day 3. Shimmer decreased from 10.07% on Day 1 to 10.00% on Day 2 but increased to 12.13% on Day 3. Harmonic-to-noise ratio increased very slightly from 13.49 on Day 1 to 14.12 on Day 2 but decreased to 12.17 on Day 3. This student's voice clarity and perturbation levels improved during the second day of heavy voice use, but he experienced a decline on the following day, possibly as muscle tension that had developed on the second day released to reveal decreased vocal efficiency on the third day.

Because this student did not likely incur any long-term damage to his vocal folds as a result of his two-day intensive period of voice use, he may not have been aware of potential long-term implications on his vocal health. But the sheer number of collisions in a developing instrument is worrisome if repeated over a long period of time, especially considering the documented changes that occurred.

By contrast, several students benefitted from coordinated institutional scheduling during the weeks they participated in the study. All students who participated in the study were enrolled in choir, but three of the four students who had no choral rehearsal during their study days were in production for a musical or opera. In two of the three cases, choral rehearsal was canceled in order to allow students to focus on the institution's opera. In the third case, choral rehearsal was canceled because the college choir had just finished an intensive weekend that culminated in a symphonic choral performance on a Sunday. This student was involved in a semi-professional off –campus musical production that opened the following weekend and, being fatigued from the intensive choral weekend, had a baseline EASE reading of 46 and a Day 1 EASE reading of 53, the highest single reading of the study. Despite the fact that she transitioned directly into a musical production week, this student had a voicing percentage of only 9.79% during her three days of monitoring, and her EASE score returned to 46 by Day 3. While she had three day means in pitch strength and HNR that were below the study mean and means in shimmer and jitter that were higher than the study mean, the vocal rest resulting from canceled choral rehearsal likely helped her get through her production week without further declines in vocal efficiency.

Clearly, the influence of voice pedagogues can either help or hinder students' ability to maintain healthy levels of voice use. The following are suggestions for college/university voice pedagogues are based on data and observations from this study:

- In sharing the initial results of this study with my own voice students, many have been very surprised to find that their greatest amount of voice use comes during non-singing periods. College and university voice pedagogues should actively engage in voice use education with all enrolled singing students, ensuring that all students understand the concept of "one larynx" and that voice use outside of rehearsal is at least as critical to their vocal health as voice use in rehearsal. Education could include reporting of data from this and other voice use studies that explain the large number of vibrations and distances traveled by the vocal folds. Voice education should include a strong and direct encouragement for serious voice students to avoid part-time jobs with high vocal demands, such as waiting tables or student telemarketing positions.
- Among the participants in this investigation, vocal dose correlates positively with inaudible changes to voice quality. Understanding that decreases in vocal efficiency

may occur well before those changes become audible, pedagogues should pay attention to students' overall schedules and avoid too much potential vocal activity during any single day when scheduling. They should not, for instance, continue to push voices through extra rehearsal in order to perfect repertoire for an upcoming concert and assume that this is not detrimental to students' vocal efficiency because there are no audible changes. Rehearsals should be coordinated between choral directors, opera/musical directors, and voice teachers to ensure that excessive vocal demands are not placed on singers at one time. For example, choral rehearsals could be limited during and opera or musical production week if a significant number of singers are involved in both activities.

- Changes in voice quality and the potential onset of vocal fatigue arise from a complex array of factors. The changes observed in this study show mostly moderate correlations between vocal dose and voice quality, indicating that vocal dose may play a part in voice quality changes but is not the sole factor behind those changes. Changes could also result from deficiencies in speaking or singing vocal technique or health issues such an acidic environment in the vocal tract, allergies, or illnesses. Vocal pedagogues should take care not to quickly assign student vocal problems to a sole factor, but understand that it may be the convergence of a variety of factors, one of which could include excessive vocal doses.
- Results of this study demonstrate that student voice quality may improve from morning to afternoon. Avoidance of early morning rehearsals could help improve student performance and confidence in rehearsals, and morning rehearsals should necessarily involve more warm-up time.

- This study develops an acoustic voice analysis method that involves recording a set of vocal tasks with a standard digital recorder and an audio microphone and analyzing those with accessible and inexpensive software. This method could be used to complete voice assessments on all incoming voice students to determine a baseline of vocal health, and it could be repeated each semester or year to see if changes are occurring. The institution will then have a baseline reading with which to compare if problems begin to manifest themselves before making a determination about visiting a laryngologist. This budget method makes voice quality analysis available to schools or private teachers without the resources of a large research university,
- In the same way, the VoxLog collar (or a similar device) could be purchased and employed with the method initially developed in this study to complete a day or more of voice dosimetry with a student experiencing vocal issues in order to determine if the problems may have a connection with voice use. While the method needs more refinement to make it easily accessible, pedagogues will eventually have a way to help students think about their voice use through a scientific analysis of what they are doing during days and hours each week that students are not with their voice teacher.
- Ongoing education about voice health throughout the school year, including regular personal check-ins with each student about their voice use outside of organized settings, should be a regular part each voice pedagogue's protocol.

It has been this pedagogue's observation that few institutions actively engage in all of the above practices. Doing so could help ensure the vocal health and success of aspiring voice professionals.

A complex array of factors informs the quality and efficiency of human vocal production. The present study seeks to enhance understanding of possible relationships between vocal dose and voice quality, both observed and perceived, among young, developing singers using data acquired in natural settings. Given the status of ambulatory voice dosimetry heretofore available, that aim became an increasingly complicated endeavor, and, thus, in some respects the current investigation is a complicated study. The primary value judgment that informed and continues to inform my work in this area is that the potential benefits for students, teachers, and researchers more than outweigh the complexities encountered in attempting a step forward toward affordable, simultaneous acquisition of vocal dose and voice quality data in non-laboratory contexts.

Succinctly put, at this study's end some questions naturally arise: "Was it worth it?" "Does the profession potentially know now more than it did when I began the study?" I believe the answer to the first question is a resounding yes, because results of this investigation reinforce many findings previously acquired in laboratory and other controlled settings while raising a host of interesting, new questions. In response to the second query, even encountered complications may advance our knowledge by spurring more refined research efforts and protocol development. In sum, this study with its unique and occasionally confounding results constitutes one, initial step towards understanding more fully by means of ambulatory dosimetry how the complex and miraculous instrument we call the human voice functions in everyday settings.

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Appendix A

Human Subjects Approval Letter

RESEARCH & GRADUATE STUDIES
The University of Kansas

APPROVAL OF PROTOCOL

September 9, 2013

Matthew Schloneger
mattschloneger@ku.edu

Dear Matthew Schloneger:

On 9/9/2013, the IRB reviewed the following submission:

Type of Review:	Initial Study
Title of Study:	Assessments of voice use, voice quality and perceived singing voice function among traditional undergraduate singing students ages 18-23 through simultaneous ambulatory monitoring with accelerometer and acoustic transducers
Investigator:	Matthew Schloneger
IRB ID:	STUDY00000140

The IRB approved the study from 9/9/2013 to 9/8/2014.

1. Before 9/8/2014 submit a Continuing Review request and required attachments to request continuing approval or closure.
2. Any significant change to the protocol requires a modification approval prior to altering the project.
3. Notify HSCL about any new investigators not named in original application. Note that new investigators must take the online tutorial at https://rgs.drupal.ku.edu/human_subjects_compliance_training.
4. Any injury to a subject because of the research procedure must be reported immediately.
5. When signed consent documents are required, the primary investigator must retain the signed consent documents for at least three years past completion of the research activity.

If continuing review approval is not granted before the expiration date of 9/8/2014 approval of this protocol expires on that date.

Please note university data security and handling requirements for your project:
https://documents.ku.edu/policies/IT/DataClassificationHandlingProceduresGuide.html

You must use the final, watermarked version of the consent form, available under the "Documents" tab in eCompliance.

Sincerely,

Stephanie Dyson Elms, MPA
IRB Administrator, KU Lawrence Campus

Human Subjects Committee Lawrence
Youngberg Hall I 2385 Irving Hill Road I Lawrence, KS 66045 I (785) 864-7429 I HSCL@ku.edu I research.ku.edu

Appendix B

Approved Participant Consent Form

Permission to Take Part in a Human Research Study

Title of research study: Assessments of voice use, voice quality and perceived singing voice function among traditional undergraduate singing students ages 18-23 through simultaneous ambulatory monitoring with accelerometer and acoustic transducers

Investigator: *Matthew Schloneger*

Why am I being invited to take part in a research study?
We invite you to take part in a research study because you are an undergraduate voice student between the ages of 18 and 23 who is enrolled in both private voice lessons and choir.

What should I know about a research study?

Someone will explain this research study to you.
Whether or not you take part is up to you.
You can choose not to take part.
You can agree to take part and later change your mind.
Your decision will not be held against you.
You can ask all the questions you want before you decide.

Who can I talk to?
If you have questions, concerns, or complaints, or think the research has hurt you, talk to the research team at 316-772-0726 or matthews@hesston.edu.

This research has been reviewed and approved by an Institutional Review Board ("IRB"). You may talk to them at (785) 864-7429 or write the Human Subjects Committee Lawrence Campus (HSCL), University of Kansas, 2385 Irving Hill Road, Lawrence, Kansas 66045-7563, email irb@ku.edu.

Your questions, concerns, or complaints are not being answered by the research team.
You cannot reach the research team.
You want to talk to someone besides the research team.
You have questions about your rights as a research subject.
You want to get information or provide input about this research.
Why is this research being done?

The purpose of this study is to assess the voice use, voice quality, and perceived singing voice function of traditional undergraduate singing students, ages 18-23 years, using both the accelerometer and acoustic transducers included in the Sonovox AB VoxLog™ portable voice analyzer collar. Undergraduate voice students' voices are still developing, and these individuals often experience heavy periods of voice use, putting them at risk for vocal problems. The VoxLog device will use two different types of microphones to simultaneously collect real-time field information about undergraduate students' "vocal dose" (how much, how high and how loud one uses their voice) and the quality of their vocal production. The data will help researchers develop an understanding of how these students use their voices, what the optimum levels of voice use for this age are, and how students might be harming their voices. The research will help in the development of recommendations for optimal vocal health and hygiene of collegiate vocalists.

How long will the research last?
We expect that you will be in this research study for all waking hours during three consecutive days while classes are in session.

How many people will be studied?
We expect about 20 people here will be in this research study out of 20 people in the entire study nationally

What happens if I say yes, I want to be in this research?
You will be asked to wear a Sonovox AB VoxLog^{TM} portable voice analyzer collar at the following times over the course of the current semester: 1) several minutes of pre-test vocal tasks today; and 2) all waking hours for three weekdays in which classes are in session, with dates to be determined by mutual consent between you and the researcher. The voice analyzer equipment consists of a VoxLog^{TM} collar that you will wear around your neck and a Roland R-05 digital recorder that you will wear in a a Tune Belt Vertical Microphone Transmitter Carrier Belt underneath your clothes on your back above the waist. At the end of each VoxLog^{TM} collar are two microphones: one microphone will sample the airborne acoustics and the other is an accelerometer that will measure only your voice use by recording skin vibrations in your neck. The collar should rest comfortably around your neck and does not require any adhesive. It connects to the digital recorder via a cable with a standard headphone jack. At today's meeting, you will complete a short vocal procedure to calibrate the unit so that we can correctly measure the amplitude of your vocal production.

The equipment can be worn during exercise, but it should not be subjected to heavy contact or become wet. If you need to remove the VoxLog for any purpose during the study period, you may do so with the Primary Investigator's permission. If the unit unexpectedly turns off during one of your three full days of monitoring, you should contact the investigator to determine the next course of action. If this occurs before less than 9 hours of monitoring is completed and the unit is not restarted shortly thereafter, you may be asked to complete an additional day of monitoring.

In addition to wearing the VoxLog collar, you will be asked to do the following:
a) Repeat four brief singing and speaking tasks while you are wearing the VoxLog collar and recording (about 5 minutes each) at the following times:

- i) Today's session in the voice studio
- ii) Three different times during each day of monitoring. You should complete the first task as early as possible and the third task as late as possible given your schedule and dormitory noise concerns. *Each task should be completed in a quiet location at least two hours after eating.*
    - a) Prior to 12pm
    - b) Between 3 and 6pm
    - c) After 8pm

b) Keep a daily time log of all activities during your three full monitoring days. This will allow the Investigator to match the voice use recorded by the VoxLog collar with your different activities. Time log sheets with more detailed instructions will be provided.
c) Complete 4 administrations of the Ability to Sing Easily (EASE) survey – once today and once during each monitoring day.
Your participation in this study will require about a 30 minute time commitment today and regular attention to tasks and documentation of your activities during all waking hours over three full days of VoxLog monitoring (about an hour of active time each day, or three hours total).

What happens if I do not want to be in this research?
You can leave the research at any time and it will not be held against you.

What happens if I say yes, but I change my mind later?
You can leave the research at any time it will not be held against you.
If you decide to leave the research, contact the investigator so that the investigator can obtain any equipment and materials related to the study that are in your possession and remove you from the study. If you decide to withdraw at any point before completing the study, your data will be discarded and not included in the final study results.

Is there any way being in this study could be bad for me?
This study involves a considerable time commitment and the inconvenience of wearing visible electronic monitoring equipment during waking hours for a total of 3 days. There is no pain, physical discomfort or physical risk associated with this study.

Will being in this study help me any way?
We cannot promise any benefits to you or others from your taking part in this research. However, possible benefits include a record of your vocal use during the study period that will be provided to you upon request after the study is completed. Your data may suggest areas for possible vocal improvement. The study is part of a larger effort to begin collecting real time voice use data among singers. These data will begin to provide a body of data about singer voice use that will help voice professionals determine why some persons develop vocal problems as well as appropriate levels of vocal use among young singers.

What happens to the information collected for the research?
To perform this study, researchers will collect information about you. This information will be obtained from a short questionnaire about your singing background and vocal health history. Efforts will be made to limit the use and disclosure of your personal information to people who have a need to review this information. We cannot promise complete secrecy. Organizations that may inspect and copy your information include the IRB and other representatives of this organization. Other researchers in the University of Kansas Vocal/Choral Pedagogy Research Group or at the National Center for Voice and Speech, which is assisting the PI with data analysis protocols, may have access to the data collected in this study.

Your name will not be associated in any way with the information collected about you or with the research findings from this study. The researcher(s) will use a study number or a pseudonym instead of your name. The researchers will not share information about you with anyone not specified above unless (a) it is required by law or university policy, or (b) you give written permission.

AUDIO RECORDING

This study will involve the digital audio recording of your voice and sounds in your immediate vicinity during all waking hours for three consecutive weekdays. These recordings will not be shared with anyone outside the research team for any reason. In order to preserve your privacy, at the end of the study before anyone ever uses the recordings, you will be given the opportunity to listen to the entire recordings and erase any portions that you don't want to be on record– no questions asked (1-3 hours additional time). All files are date and time stamped. We will not analyze the content of your recordings or play them for anyone outside the research team, and you do have the opportunity to erase any material at the end of the study. Even so, in some instances you may still prefer not to be recorded in the first place. In these situations, you can simply turn off the VoxLog monitor and then turn it on when you are comfortable recording again. If you do turn off the unit for this reason, please mark the beginning and ending time that the unit was turned off in your activity log .

You will also record the voices of other people in your vicinity during the course of this study. According to Kanas law, only your consent is required to complete this recording study. While you may wish to inform those around you that you are being recorded, the written consent of others is not necessary or required for you to record their voices if they are standing near enough to you to be recorded.

Your audio files will initially be stored on an SD card placed in the audio recorder. After you complete your monitoring days, the files will be transferred to a password protected computer hard drive and immediately deleted from the SD card. The files will also be stored in a password protected cloud file for backup purposes. The members of the research team listed below will be the only persons allowed access to these files, and only the primary investigator will have the means to identify the individual who completed that recording. You may also request a personal copy of your audio files upon completion of the study.

Permission granted on this date to use and disclose your information remains in effect indefinitely. The Principal Investigator will retain the audio files and printed records obtained by this study in secure password protected digital files indefinitely for future research. By signing this form you give permission for the use and disclosure of your information for purposes of this study at any time in the future.

Can I be removed from the research without my OK?

The person in charge of the research study or the sponsor can remove you from the research study without your approval. Possible reasons for removal include not meeting all of the following criteria: 1) You are currently enrolled in both voice lessons and a choral ensemble at a college or university, 2) You are aged 18-24 years, or 3) You report having a current unresolved vocal pathology. You may also be withdrawn without their consent if you demonstrate reckless behavior in regards to the electronic equipment.

What else do I need to know?
Participating students enrolled in Private Voice lessons at Hesston College, where Principal Investigator Matthew Schloneger is the primary Voice Instructor, will receive extra course credit for participating in this study. There will absolutely no penalty for Hesston College voice students who chose not to participate in or complete this study.

Signature Block for Capable Adult
Your signature documents your permission to take part in this research.

Signature of subject	Date
Printed name of subject	
Signature of person obtaining consent	Date
Printed name of person obtaining consent	IRB Approval Date

Appendix C

Participant Demographic Survey

PARTICIPANT QUESTIONNAIRE

Circle One: MALE FEMALE

Your age: _____years

Semesters enrolled in college (if you are an incoming freshman, write zero) _______

Circle One:
I am currently singing in a college/university choir. YES NO

I am currently enrolled in voice lessons through my college/university. YES NO

In addition to choir and voice lessons, I will have other regular singing commitments this semester:
YES NO

If you answered yes, please list the activity and the estimated hours per week of singing commitment:

Activity____ Hrs/Week_____

Activity____ Hrs/Week_____

Activity____ Hrs/Week_____

Please indicate previous years of regular, ongoing choir member ship in any kind of choir (including school, church, and/or community choirs). If none, write zero. If less than one year, write less than 1 year:
____ years

Please indicate number of years of any regular, ongoing VOICE LESSONS with a private teacher (If none, write zero. If less than one year, write less than 1 year): _______ years

Have you ever dealt with a serious vocal injury (nodules, polyp, etc.)? YES NO

If yes, please respond to following: Date diagnosed________________

Condition__________________ Is the issue resolved? YES NO

Have you ever worked with a Speech Language Pathologist to resolve issues related to your voice?
(circle one) YES NO

Can you sing the first verse of “Amazing Grace” from memory? (circle one) YES NO

Would you like to receive a report on your personal voice use following the completion of this study?
(circle one) * YES NO

*Please note that if you indicate “yes,” a document will be maintained that identifies all of your information with you until after the study is complete. If you circle “no,” your records will not by directly identified with you after the data collection is complete.

Appendix D

Participant Activity Log

Vocal Dosage Study
Daily Activity Log

Participant Number ______
Date______________

Carry this form with you during each day you wear the VoxLog unit. Record the type and duration of activities during which you used your voice (speaking or singing) for periods exceeding fifteen minutes, e.g., a rehearsal, a social event, a meeting, a ballgame, a discussion class, etc. Please also record the three times at which you complete the assigned vocal tasks. For each activity, try to use the exact hour and minute listed on your cell phone.

ACTIVITY	TIME COMMENCED	TIME ENDED

Appendix E

Evaluation of Ability to Sing Easily (EASE) Questionnaire

Evaluation of the Ability to Sing Easily (EASE)

		Not at All	Mildly	Moderately	Extremely
1.	My voice is husky	1	2	3	4
2.	My voice is dry/scratchy	1	2	3	4
3.	My throat muscles are feeling overworked	1	2	3	4
4.	My voice feels good	1	2	3	4
5.	My top notes are breathy	1	2	3	4
6.	The onsets of my notes are delayed or breathy	1	2	3	4
7.	My voice sounds rich and resonant	1	2	3	4
8.	My voice is ready for performance if required	1	2	3	4
9.	My voice is tired	1	2	3	4
10.	My voice is worse than usual	1	2	3	4
11.	My voice cracks and breaks	1	2	3	4
12.	My voice is breathy	1	2	3	4
13.	I am having difficulty with my breath for long phrases	1	2	3	4
14.	My voice is cutting out on some notes	1	2	3	4
15.	I am having difficulty changing registers	1	2	3	4
16.	I am having difficulty with my high notes	1	2	3	4
17.	I am having difficulty projecting my voice	1	2	3	4
18.	I am having difficulty singing softly	1	2	3	4
19.	Singing is hard work	1	2	3	4
20.	I am having difficulty sustaining long notes	1	2	3	4
21.	I am worried about my voice	1	2	3	4
22.	I am concerned about my voice	1	2	3	4

Appendix F

Complete List of Research and Sub-Research Questions

Note: The research questions listed in Chapter One appear in bold print.

1. **Are there statistically significant relationships between each of four measures of student vocal dose (phonation percentage, dose time, cycle dose, and distance dose) and each of ten measures of voice quality (F_0, P_0, dB SPL, LTAS slope, alpha ratio, dB SPL 1-3 kHz, pitch strength, shimmer, jitter, and harmonic-to-noise ratio) acquired with the VoxLog collar's unfiltered accelerometer signal a) over three full days of ambulatory monitoring and b) between three types of activities (non-singing, choral singing and solo singing)?**
   A. As acquired by the VoxLog collar's unfiltered accelerometer signal over three full days of ambulatory monitoring,
      1. Is there a statistically significant correlation between phonation percentage and F_0?
      2. Is there a statistically significant correlation between phonation percentage and P_0?
      3. Is there a statistically significant correlation between phonation percentage and dB SPL?
      4. Is there a statistically significant correlation between phonation percentage and LTAS slope?
      5. Is there a statistically significant correlation between phonation percentage and alpha ratio?
      6. Is there a statistically significant correlation between phonation percentage and dB SPL 1-3 kHz?
      7. Is there a statistically significant correlation between phonation percentage and pitch strength?
      8. Is there a statistically significant correlation between phonation percentage and shimmer?
      9. Is there a statistically significant correlation between phonation percentage and jitter?
      10. Is there a statistically significant correlation between phonation percentage and HNR?
      11. Is there a statistically significant correlation between Dt and F_0?
      12. Is there a statistically significant correlation between Dt and P_0?
      13. Is there a statistically significant correlation between Dt and dB SPL?
      14. Is there a statistically significant correlation between Dt and LTAS slope?
      15. Is there a statistically significant correlation between Dt and alpha ratio?
      16. Is there a statistically significant correlation between Dt and dB SPL 1-3 kHz??
      17. Is there a statistically significant correlation between Dt and pitch strength?
      18. Is there a statistically significant correlation between Dt and shimmer?
      19. Is there a statistically significant correlation between Dt and jitter?
      20. Is there a statistically significant correlation between Dt and HNR?
      21. Is there a statistically significant correlation between Dc and dB SPL?
      22. Is there a statistically significant correlation between Dc and LTAS slope?
      23. Is there a statistically significant correlation between Dc and alpha ratio?
      24. Is there a statistically significant correlation between Dcand dB SPL 1-3 kHz??
      25. Is there a statistically significant correlation between Dc and pitch strength?

26. Is there a statistically significant correlation between Dcand shimmer?
27. Is there a statistically significant correlation between Dc and jitter?
28. Is there a statistically significant correlation between Dcand HNR?
29. Is there a statistically significant correlation between Dd and LTAS slope?
30. Is there a statistically significant correlation between Dd and alpha ratio?
31. Is there a statistically significant correlation between Dd and dB SPL 1-3 kHz??
32. Is there a statistically significant correlation between Dd and pitch strength?
33. Is there a statistically significant correlation between Dd and shimmer?
34. Is there a statistically significant correlation between Dd and jitter?
35. Is there a statistically significant correlation between Dd and HNR?

B. As acquired by the VoxLog collar's unfiltered accelerometer signal
    1. Over three full days of ambulatory monitoring, are there statistically significant differences in:
        a. Phonation percentage readings among three different activities (non-singing, choral singing and solo singing)?
        b. Dt readings among three different activities (non-singing, choral singing and solo singing)?
        c. Dc readings among three different activities (non-singing, choral singing and solo singing)?
        d. Dd readings among three different activities (non-singing, choral singing and solo singing)?
        e. F_0 readings among three different activities (non-singing, choral singing and solo singing)?
        f. P_0 readings among three different activities (non-singing, choral singing and solo singing)?
        g. dB SPL readings among three different activities (non-singing, choral singing and solo singing)?
        h. LTAS slope readings among three different activities (non-singing, choral singing and solo singing)?
        i. Alpha ratio readings among three different activities (non-singing, choral singing and solo singing)?
        j. dB SPL 1-3 kHz readings among three different activities (non-singing, choral singing and solo singing)?
        k. Pitch strength readings among three different activities (non-singing, choral singing and solo singing)?
        l. Shimmer readings among three different activities (non-singing, choral singing and solo singing)?
        m. Jitter readings among three different activities (non-singing, choral singing and solo singing)?
        n. HNR readings among three different activities (non-singing, choral singing and solo singing)?
    2. Are there statistically significant correlations in terms three *full day* voice quality readings between:
        a. Total minutes recorded of singing time over three days and dB SPL
        b. Total minutes recorded of singing time over three days and pitch strength
        c. Total minutes recorded of singing time over three days and HNR

d. Total minutes recorded of singing time over three days and jitter
e. Total minutes recorded of singing time over three days and shimmer
f. Three day singing Dt and dB SPL
g. Three day singing Dt and pitch strength
h. Three day singing Dt and HNR
i. Three day singing Dt and jitter
j. Three day singing Dt and shimmer
k. Three day singing Dc and dB SPL
l. Three day singing Dc and pitch strength
m. Three day singing Dc and HNR
n. Three day singing Dc and jitter
o. Three day singing Dc and shimmer
p. Three day singing Dd and dB SPL
q. Three day singing Dd and pitch strength
r. Three day singing Dd and HNR
s. Three day singing Dd and jitter
t. Three day singing Dd and shimmer
u. Three day non-singing Dt and dB SPL
v. Three day non-singing Dt and pitch strength
w. Three day non-singing Dt and HNR
x. Three day non-singing Dt and jitter
y. Three day non-singing Dt and shimmer
z. Three day non-singing Dc and dB SPL
aa. Three day non-singing Dc and pitch strength
bb. Three day non-singing Dc and HNR
cc. Three day non-singing Dc and jitter
dd. Three day non-singing Dc and shimmer
ee. Three day non-singing Dd and dB SPL
ff. Three day non-singing Dd and pitch strength
gg. Three day non-singing Dd and HNR
hh. Three day non-singing Dd and jitter
ii. Three day non-singing Dd and shimmer

3. Are there statistically significant correlations in terms of voice quality readings during *non-singing periods* over three days of ambulatory monitoring between:
    a. Three day non-singing Dt and dB SPL
    b. Three day non-singing Dt and pitch strength
    c. Three day non-singing Dt and HNR
    d. Three day Three day non-singing Dt and jitter
    e. Three day non-singing Dt and shimmer
    f. Three day non-singing Dc and dB SPL
    g. Three day non-singing Dc and pitch strength
    h. Three day non-singing Dc and HNR
    i. Three day non-singing Dc and jitter
    j. Three day non-singing Dc and shimmer
    k. Three day non-singing Dd and dB SPL
    l. Three day non-singing Dd and pitch strength

m. Three day non-singing Dd and HNR
n. Three day non-singing Dd and jitter
o. Three day non-singing Dd and shimmer

2. **Are there statistically significant differences across time in each of ten measures of voice quality (F_0, P_0, dB SPL, LTAS slope, alpha ratio, dB SPL 1-3 kHz, pitch strength, shimmer, jitter, and harmonic-to-noise ratio) acquired with the VoxLog collar's acoustic neck microphone :**
   A. **between the mean morning, afternoon, and evening measurements of singing and speaking vocal tasks?**
      1. As acquired during a spoken /a/ vocal task,
         a. Are there significant changes across time in F_0?
         b. Are there significant changes across time in P_0?
         c. Are there significant changes across time in dB SPL?
         d. Are there significant changes across time in LTAS slope?
         e. Are there significant changes across time in alpha ratio?
         f. Are there significant changes across time in dB SPL 1-3 kHz??
         g. Are there significant changes across time in pitch strength?
         h. Are there significant changes across time in shimmer?
         i. Are there significant changes across time in jitter?
         j. Are there significant changes across time in HNR?
      2. As acquired during a sung /a/ task,
         a. Are there significant changes across time in F_0?
         b. Are there significant changes across time in P_0?
         c. Are there significant changes across time in dB SPL?
         d. Are there significant changes across time in LTAS slope?
         e. Are there significant changes across time in alpha ratio?
         f. Are there significant changes across time in dB SPL 1-3 kHz??
         g. Are there significant changes across time in pitch strength?
         h. Are there significant changes across time in shimmer?
         i. Are there significant changes across time in jitter?
         j. Are there significant changes across time in HNR??
      3. As acquired during the Amazing Grace singing task,
         a. Are there significant changes across time in F_0?
         b. Are there significant changes across time in P_0?
         c. Are there significant changes across time in dB SPL?
         d. Are there significant changes across time in LTAS slope?
         e. Are there significant changes across time in alpha ratio?
         f. Are there significant changes across time in dB SPL 1-3 kHz??
         g. Are there significant changes across time in pitch strength?
         h. Are there significant changes across time in shimmer?
         i. Are there significant changes across time in jitter?
         j. Are there significant changes across time in HNR?
      4. As acquired during the Rainbow Passage speaking task,
         a. Are there significant changes across time in F_0?
         b. Are there significant changes across time in P_0?

c. Are there significant changes across time in dB SPL?
d. Are there significant changes across time in LTAS slope?
e. Are there significant changes across time in alpha ratio?
f. Are there significant changes across time in dB SPL 1-3 kHz??
g. Are there significant changes across time in pitch strength?
h. Are there significant changes across time in shimmer?
i. Are there significant changes across time in jitter?
j. Are there significant changes across time in HNR?

B. between a baseline reading of speaking and singing vocal tasks and mean readings of these vocal tasks acquired during three days of monitoring?

1. As acquired during a spoken /a/ vocal task,
   a. Are there significant differences across time in F_0?
   b. Are there significant differences across time in P_0?
   c. Are there significant differences across time in dB SPL?
   d. Are there significant differences across time in LTAS slope?
   e. Are there significant differences across time in alpha ratio?
   f. Are there significant differences across time in dB SPL 1-3 kHz??
   g. Are there significant differences across time in pitch strength?
   h. Are there significant differences across time in shimmer?
   i. Are there significant differences across time in jitter?
   j. Are there significant differences across time in HNR?
2. As acquired during a sung /a/ task,
   a. Are there significant differences across time in F_0?
   b. Are there significant differences across time in P_0?
   c. Are there significant differences across time in dB SPL?
   d. Are there significant differences across time in LTAS slope?
   e. Are there significant differences across time in alpha ratio?
   f. Are there significant differences across time in dB SPL 1-3 kHz??
   g. Are there significant differences across time in pitch strength?
   h. Are there significant differences across time in shimmer?
   i. Are there significant differences across time in jitter?
   j. Are there significant differences across time in HNR?
3. As acquired during the Amazing Grace singing task,
   a. Are there significant differences across time in F_0?
   b. Are there significant differences across time in P_0?
   c. Are there significant differences across time in dB SPL?
   d. Are there significant differences across time in LTAS slope?
   e. Are there significant differences across time in alpha ratio?
   f. Are there significant differences across time in dB SPL 1-3 kHz??
   g. Are there significant differences across time in pitch strength?
   h. Are there significant differences across time in shimmer?
   i. Are there significant differences across time in jitter?
   j. Are there significant differences across time in HNR?
4. As acquired during the Rainbow Passage speaking task,
   a. Are there significant differences across time in F_0?
   b. Are there significant differences across time in P_0?

c. Are there significant differences across time in dB SPL?
d. Are there significant differences across time in LTAS slope?
e. Are there significant differences across time in alpha ratio?
f. Are there significant differences across time in dB SPL 1-3 kHz??
g. Are there significant differences across time in pitch strength?
h. Are there significant differences across time in shimmer?
i. Are there significant differences across time in jitter?
j. Are there significant differences across time in HNR?

3. **What do participants' scores on the validated Ability to Sing Easily (EASE) questionnaire suggest about their perceptions of voice function during the course of this study?**
   A. Are there significant changes in EASE scores between a baseline administration and administrations completed at the end of each of three days of ambulatory monitoring?
   B. Are there a significant difference between student's sex and mean three day EASE scores, including the total and three subset EASE scores?
   C. Are there significant correlations between students' age and mean three day EASE scores, including the total and three subset EASE scores?
   D. Are there significant correlations s between students' years of choral experience and mean three day EASE scores, including the total and three subset EASE scores?
   E. Are there significant correlations between students' years of voice lessons and mean three day EASE scores, including the total and three subset EASE scores?

4. **Are there statistically significant relationships among each of four measures of participants' vocal dose over three days, each of ten measures of voice quality acquired through vocal tasks, EASE scores, participant sex, age, and amount/types of singing experience?**
   A. Are there significant correlations between students' mean EASE scores and fourteen measures of vocal dose and voice quality acquired through ambulatory monitoring?
      1. Are there significant correlations between students' three day mean EASE scores and:
         a. Voicing percentage acquired during three days of ambulatory monitoring?
         b. Dt acquired during three days of ambulatory monitoring?
         c. Dc acquired during three days of ambulatory monitoring?
         d. Dc acquired during three days of ambulatory monitoring?
         e. Mean F_0 acquired during three days of ambulatory monitoring?
         f. Mean P_0 acquired during three days of ambulatory monitoring?
         g. Mean dB SPL acquired during three days of ambulatory monitoring?
         h. Mean LTAS slope acquired during three days of ambulatory monitoring?
         i. Mean alpha ratio acquired during three days of ambulatory monitoring?
         j. Mean dB SPL 1-3 kHz acquired during three days of ambulatory monitoring?

- k. Mean pitch strength acquired during three days of ambulatory monitoring?
- l. Mean shimmer acquired during three days of ambulatory monitoring?
- m. Mean jitter acquired during three days of ambulatory monitoring?
- n. Mean HNR acquired during three days of ambulatory monitoring?

2. Is there a significant relationship between the measured difference between the baseline EASE score and the final monitoring day's EASE score and:
   - a. Voicing percentage acquired during three days of ambulatory monitoring?
   - b. Dt acquired during three days of ambulatory monitoring?
   - c. Dc acquired during three days of ambulatory monitoring?
   - d. Dc acquired during three days of ambulatory monitoring?
   - e. Mean F_0 acquired during three days of ambulatory monitoring?
   - f. Mean P_0 acquired during three days of ambulatory monitoring?
   - g. Mean dB SPL acquired during three days of ambulatory monitoring?
   - h. Mean LTAS slope acquired during three days of ambulatory monitoring?
   - i. Mean alpha ratio acquired during three days of ambulatory monitoring?
   - j. Mean dB SPL 1-3 kHz acquired during three days of ambulatory monitoring?
   - k. Mean pitch strength acquired during three days of ambulatory monitoring?
   - l. Mean shimmer acquired during three days of ambulatory monitoring?
   - m. Mean jitter acquired during three days of ambulatory monitoring?
   - n. Mean HNR acquired during three days of ambulatory monitoring?

B. Are there significant correlations between students' mean EASE scores and
   - a. Mean F_0 of all aggregated vocal tasks?
   - b. Mean P_0 of all aggregated vocal tasks?
   - c. Mean dB SPL of all aggregated vocal tasks?
   - d. Mean LTAS slope of all aggregated vocal tasks?
   - e. Mean alpha ratio of all aggregated vocal tasks?
   - f. Mean dB SPL 1-3 kHz of all aggregated vocal tasks?
   - g. Mean pitch strength of all aggregated vocal tasks?
   - h. Mean shimmer of all aggregated vocal tasks?
   - i. Mean jitter of all aggregated vocal tasks?
   - j. Mean HNR of all aggregated vocal tasks?

C. Are there significant correlations between students' demographic information (sex, age, years of singing experience and years of choral experience) and fourteen measures of vocal dose and voice quality acquired through ambulatory monitoring?
   1. Is there a significant relationship between students' sex and:
      - a. Voicing percentage acquired during three days of ambulatory monitoring?
      - b. Dt acquired during three days of ambulatory monitoring?
      - c. Dc acquired during three days of ambulatory monitoring?
      - d. Dc acquired during three days of ambulatory monitoring?

e. Mean F_0 acquired during three days of ambulatory monitoring?
f. Mean P_0 acquired during three days of ambulatory monitoring?
g. Mean dB SPL acquired during three days of ambulatory monitoring?
h. Mean LTAS slope acquired during three days of ambulatory monitoring?
i. Mean alpha ratio acquired during three days of ambulatory monitoring?
j. Mean dB SPL 1-3 kHz acquired during three days of ambulatory monitoring?
k. Mean pitch strength acquired during three days of ambulatory monitoring?
l. Mean shimmer acquired during three days of ambulatory monitoring?
m. Mean jitter acquired during three days of ambulatory monitoring?
n. Mean HNR acquired during three days of ambulatory monitoring?

2. Are there significant correlations between students' age and:
    a. Voicing percentage acquired during three days of ambulatory monitoring?
    b. Dt acquired during three days of ambulatory monitoring?
    c. Dc acquired during three days of ambulatory monitoring?
    d. Dc acquired during three days of ambulatory monitoring?
    e. Mean F_0 acquired during three days of ambulatory monitoring?
    f. Mean P_0 acquired during three days of ambulatory monitoring?
    g. Mean dB SPL acquired during three days of ambulatory monitoring?
    h. Mean LTAS slope acquired during three days of ambulatory monitoring?
    i. Mean alpha ratio acquired during three days of ambulatory monitoring?
    j. Mean dB SPL 1-3 kHz acquired during three days of ambulatory monitoring?
    k. Mean pitch strength acquired during three days of ambulatory monitoring?
    l. Mean shimmer acquired during three days of ambulatory monitoring?
    m. Mean jitter acquired during three days of ambulatory monitoring?
    n. Mean HNR acquired during three days of ambulatory monitoring?
3. Are there significant correlations between students' choral experience and:
    a. Voicing percentage acquired during three days of ambulatory monitoring?
    b. Dt acquired during three days of ambulatory monitoring?
    c. Dc acquired during three days of ambulatory monitoring?
    d. Dc acquired during three days of ambulatory monitoring?
    e. Mean F_0 acquired during three days of ambulatory monitoring?
    f. Mean P_0 acquired during three days of ambulatory monitoring?
    g. Mean dB SPL acquired during three days of ambulatory monitoring?
    h. Mean LTAS slope acquired during three days of ambulatory monitoring?

i. Mean alpha ratio acquired during three days of ambulatory monitoring?
j. Mean dB SPL 1-3 kHz acquired during three days of ambulatory monitoring?
k. Mean pitch strength acquired during three days of ambulatory monitoring?
l. Mean shimmer acquired during three days of ambulatory monitoring?
m. Mean jitter acquired during three days of ambulatory monitoring?
n. Mean HNR acquired during three days of ambulatory monitoring?
o. Mean HNR of all aggregated vocal tasks?

4. Are there significant correlations between students' voice lesson experience and:
    a. Voicing percentage acquired during three days of ambulatory monitoring?
    b. Dt acquired during three days of ambulatory monitoring?
    c. Dc acquired during three days of ambulatory monitoring?
    d. Dc acquired during three days of ambulatory monitoring?
    e. Mean F_0 acquired during three days of ambulatory monitoring?
    f. Mean P_0 acquired during three days of ambulatory monitoring?
    g. Mean dB SPL acquired during three days of ambulatory monitoring?
    h. Mean LTAS slope acquired during three days of ambulatory monitoring?
    i. Mean alpha ratio acquired during three days of ambulatory monitoring?
    j. Mean dB SPL 1-3 kHz acquired during three days of ambulatory monitoring?
    k. Mean pitch strength acquired during three days of ambulatory monitoring?
    l. Mean shimmer acquired during three days of ambulatory monitoring?
    m. Mean jitter acquired during three days of ambulatory monitoring?
    n. Mean HNR acquired during three days of ambulatory monitoring?

D. Are there significant correlations between student's demographic information (sex, age, years of singing experience and years of choral experience) and ten measures of voice quality acquired through the administration of ten repetitions of four vocal tasks?
  1. Is there a significant relationship between students' sex and:
      a. Mean F_0 of the spoken /a/ task?
      b. Mean P_0 of the spoken /a/ task?
      c. Mean dB SPL of the spoken /a/ task?
      d. Mean LTAS of the spoken /a/ task?
      e. Mean alpha ratio of the spoken a/ task?
      f. Mean dB SPL 1-3 kHz of the spoken /a/ task?
      g. Mean pitch strength of the spoken /a/ task?
      h. Mean shimmer of the spoken /a/ task?
      i. Mean jitter of the spoken /a/ task?
      j. Mean HNR of the spoken /a/ task?

k. Mean F_0 of the sung /a/ task?
l. Mean P_0 of the sung /a/ task?
m. Mean dB SPL of the sung /a/ task?
n. Mean LTAS of the sung /a/ task?
o. Mean alpha ratio of the sung /a/ task?
p. Mean dB SPL 1-3 kHz of the sung /a/ task?
q. Mean pitch strength of the sung /a/ task?
r. Mean shimmer of the sung /a/ task?
s. Mean jitter of the sung /a/ task?
t. Mean HNR of the sung /a/ task?
u. Mean F_0 of the Amazing Grace task?
v. Mean P_0 of the Amazing Grace task?
w. Mean dB SPL of the Amazing Grace task?
x. Mean LTAS of the Amazing Grace task?
y. Mean alpha ratio of the Amazing Grace task?
z. Mean dB SPL 1-3 kHz of the Amazing Grace task?
aa. Mean pitch strength of the Amazing Grace task?
bb. Mean shimmer of the Amazing Grace task?
cc. Mean jitter of the Amazing Grace task?
dd. Mean HNR of the Amazing Grace task?
ee. Mean F_0 of the Rainbow Passage task?
ff. Mean P_0 of the Rainbow Passage task?
gg. Mean dB SPL of the Rainbow Passage task?
hh. Mean LTAS of the Rainbow Passage task?
ii. Mean alpha ratio of the Rainbow Passage task?
jj. Mean dB SPL 1-3 kHz of the Rainbow Passage task?
kk. Mean pitch strength of the Rainbow Passage task?
ll. Mean shimmer of the Rainbow Passage task?
mm. Mean jitter of the Rainbow Passage task?
nn. Mean HNR of the Rainbow Passage task?

2. Are there significant correlations between students' age and:
   a. Mean F_0 of the spoken /a/ task?
   b. Mean P_0 of the spoken /a/ task?
   c. Mean dB SPL of the spoken /a/ task?
   d. Mean LTAS of the spoken /a/ task?
   e. Mean alpha ratio of the spoken a/ task?
   f. Mean dB SPL 1-3 kHz of the spoken /a/ task?
   g. Mean pitch strength of the spoken /a/ task?
   h. Mean shimmer of the spoken /a/ task?
   i. Mean jitter of the spoken /a/ task?
   j. Mean HNR of the spoken /a/ task?
   k. Mean F_0 of the sung /a/ task?
   l. Mean P_0 of the sung /a/ task?
   m. Mean dB SPL of the sung /a/ task?
   n. Mean LTAS of the sung /a/ task?
   o. Mean alpha ratio of the sung /a/ task?

p. Mean dB SPL 1-3 kHz of the sung /a/ task?
q. Mean pitch strength of the sung /a/ task?
r. Mean shimmer of the sung /a/ task?
s. Mean jitter of the sung /a/ task?
t. Mean HNR of the sung /a/ task?
u. Mean F_0 of the Amazing Grace task?
v. Mean P_0 of the Amazing Grace task?
w. Mean dB SPL of the Amazing Grace task?
x. Mean LTAS of the Amazing Grace task?
y. Mean alpha ratio of the Amazing Grace task?
z. Mean dB SPL 1-3 kHz of the Amazing Grace task?
aa. Mean pitch strength of the Amazing Grace task?
bb. Mean shimmer of the Amazing Grace task?
cc. Mean jitter of the Amazing Grace task?
dd. Mean HNR of the Amazing Grace task?
ee. Mean F_0 of the Rainbow Passage task?
ff. Mean P_0 of the Rainbow Passage task?
gg. Mean dB SPL of the Rainbow Passage task?
hh. Mean LTAS of the Rainbow Passage task?
ii. Mean alpha ratio of the Rainbow Passage task?
jj. Mean dB SPL 1-3 kHz of the Rainbow Passage task?
kk. Mean pitch strength of the Rainbow Passage task?
ll. Mean shimmer of the Rainbow Passage task?
mm. Mean jitter of the Rainbow Passage task?
nn. Mean HNR of the Rainbow Passage task?

3. Are there significant correlations between students' choral experience and:
    a. Mean F_0 of the spoken /a/ task?
    b. Mean P_0 of the spoken /a/ task?
    c. Mean dB SPL of the spoken /a/ task?
    d. Mean LTAS of the spoken /a/ task?
    e. Mean alpha ratio of the spoken a/ task?
    f. Mean dB SPL 1-3 kHz of the spoken /a/ task?
    g. Mean pitch strength of the spoken /a/ task?
    h. Mean shimmer of the spoken /a/ task?
    i. Mean jitter of the spoken /a/ task?
    j. Mean HNR of the spoken /a/ task?
    k. Mean F_0 of the sung /a/ task?
    l. Mean P_0 of the sung /a/ task?
    m. Mean dB SPL of the sung /a/ task?
    n. Mean LTAS of the sung /a/ task?
    o. Mean alpha ratio of the sung /a/ task?
    p. Mean dB SPL 1-3 kHz of the sung /a/ task?
    q. Mean pitch strength of the sung /a/ task?
    r. Mean shimmer of the sung /a/ task?
    s. Mean jitter of the sung /a/ task?
    t. Mean HNR of the sung /a/ task?

u. Mean F_0 of the Amazing Grace task?
v. Mean P_0 of the Amazing Grace task?
w. Mean dB SPL of the Amazing Grace task?
x. Mean LTAS of the Amazing Grace task?
y. Mean alpha ratio of the Amazing Grace task?
z. Mean dB SPL 1-3 kHz of the Amazing Grace task?
aa. Mean pitch strength of the Amazing Grace task?
bb. Mean shimmer of the Amazing Grace task?
cc. Mean jitter of the Amazing Grace task?
dd. Mean HNR of the Amazing Grace task?
ee. Mean F_0 of the Rainbow Passage task?
ff. Mean P_0 of the Rainbow Passage task?
gg. Mean dB SPL of the Rainbow Passage task?
hh. Mean LTAS of the Rainbow Passage task?
ii. Mean alpha ratio of the Rainbow Passage task?
jj. Mean dB SPL 1-3 kHz of the Rainbow Passage task?
kk. Mean pitch strength of the Rainbow Passage task?
ll. Mean shimmer of the Rainbow Passage task?
mm. Mean jitter of the Rainbow Passage task?
nn. Mean HNR of the Rainbow Passage task?

4. Are there significant correlations between students' voice lesson experience and:
    a. Mean F_0 of the spoken /a/ task?
    b. Mean P_0 of the spoken /a/ task?
    c. Mean dB SPL of the spoken /a/ task?
    d. Mean LTAS of the spoken /a/ task?
    e. Mean alpha ratio of the spoken a/ task?
    f. Mean dB SPL 1-3 kHz of the spoken /a/ task?
    g. Mean pitch strength of the spoken /a/ task?
    h. Mean shimmer of the spoken /a/ task?
    i. Mean jitter of the spoken /a/ task?
    j. Mean HNR of the spoken /a/ task?
    k. Mean F_0 of the sung /a/ task?
    l. Mean P_0 of the sung /a/ task?
    m. Mean dB SPL of the sung /a/ task?
    n. Mean LTAS of the sung /a/ task?
    o. Mean alpha ratio of the sung /a/ task?
    p. Mean dB SPL 1-3 kHz of the sung /a/ task?
    q. Mean pitch strength of the sung /a/ task?
    r. Mean shimmer of the sung /a/ task?
    s. Mean jitter of the sung /a/ task?
    t. Mean HNR of the sung /a/ task?
    u. Mean F_0 of the Amazing Grace task?
    v. Mean P_0 of the Amazing Grace task?
    w. Mean dB SPL of the Amazing Grace task?
    x. Mean LTAS of the Amazing Grace task?

y. Mean alpha ratio of the Amazing Grace task?
z. Mean dB SPL 1-3 kHz of the Amazing Grace task?
aa. Mean pitch strength of the Amazing Grace task?
bb. Mean shimmer of the Amazing Grace task?
cc. Mean jitter of the Amazing Grace task?
dd. Mean HNR of the Amazing Grace task?
ee. Mean F_0 of the Rainbow Passage task?
ff. Mean P_0 of the Rainbow Passage task?
gg. Mean dB SPL of the Rainbow Passage task?
hh. Mean LTAS of the Rainbow Passage task?
ii. Mean alpha ratio of the Rainbow Passage task?
jj. Mean dB SPL 1-3 kHz of the Rainbow Passage task?
kk. Mean pitch strength of the Rainbow Passage task?
ll. Mean shimmer of the Rainbow Passage task?
mm. Mean jitter of the Rainbow Passage task?
nn. Mean HNR of the Rainbow Passage task?

E. Are there significant correlations between each of four measures of vocal dose acquired through ambulatory monitoring and each of ten measures of voice quality acquired through the repeated administration of four vocal tasks?

1. Is there a significant correlation between voicing percentage acquired during three days of ambulatory monitoring and:
    a. Mean F_0 of the spoken /a/ task?
    b. Mean P_0 of the spoken /a/ task?
    c. Mean dB SPL of the spoken /a/ task?
    d. Mean LTAS of the spoken /a/ task?
    e. Mean alpha ratio of the spoken a/ task?
    f. Mean dB SPL 1-3 kHz of the spoken /a/ task?
    g. Mean pitch strength of the spoken /a/ task?
    h. Mean shimmer of the spoken /a/ task?
    i. Mean jitter of the spoken /a/ task?
    j. Mean HNR of the spoken /a/ task?
    k. Mean F_0 of the sung /a/ task?
    l. Mean P_0 of the sung /a/ task?
    m. Mean dB SPL of the sung /a/ task?
    n. Mean LTAS of the sung /a/ task?
    o. Mean alpha ratio of the sung /a/ task?
    p. Mean dB SPL 1-3 kHz of the sung /a/ task?
    q. Mean pitch strength of the sung /a/ task?
    r. Mean shimmer of the sung /a/ task?
    s. Mean jitter of the sung /a/ task?
    t. Mean HNR of the sung /a/ task?
    u. Mean F_0 of the Amazing Grace task?
    v. Mean P_0 of the Amazing Grace task?
    w. Mean dB SPL of the Amazing Grace task?
    x. Mean LTAS of the Amazing Grace task?
    y. Mean alpha ratio of the Amazing Grace task?

z. Mean dB SPL 1-3 kHz of the Amazing Grace task?
aa. Mean pitch strength of the Amazing Grace task?
bb. Mean shimmer of the Amazing Grace task?
cc. Mean jitter of the Amazing Grace task?
dd. Mean HNR of the Amazing Grace task?
ee. Mean F_0 of the Rainbow Passage task?
ff. Mean P_0 of the Rainbow Passage task?
gg. Mean dB SPL of the Rainbow Passage task?
hh. Mean LTAS of the Rainbow Passage task?
ii. Mean alpha ratio of the Rainbow Passage task?
jj. Mean dB SPL 1-3 kHz of the Rainbow Passage task?
kk. Mean pitch strength of the Rainbow Passage task?
ll. Mean shimmer of the Rainbow Passage task?
mm. Mean jitter of the Rainbow Passage task?
nn. Mean HNR of the Rainbow Passage task?

2. Is there a significant correlation between Dt acquired during three days of ambulatory monitoring and:
    a. Mean F_0 of the spoken /a/ task?
    b. Mean P_0 of the spoken /a/ task?
    c. Mean dB SPL of the spoken /a/ task?
    d. Mean LTAS of the spoken /a/ task?
    e. Mean alpha ratio of the spoken a/ task?
    f. Mean dB SPL 1-3 kHz of the spoken /a/ task?
    g. Mean pitch strength of the spoken /a/ task?
    h. Mean shimmer of the spoken /a/ task?
    i. Mean jitter of the spoken /a/ task?
    j. Mean HNR of the spoken /a/ task?
    k. Mean F_0 of the sung /a/ task?
    l. Mean P_0 of the sung /a/ task?
    m. Mean dB SPL of the sung /a/ task?
    n. Mean LTAS of the sung /a/ task?
    o. Mean alpha ratio of the sung /a/ task?
    p. Mean dB SPL 1-3 kHz of the sung /a/ task?
    q. Mean pitch strength of the sung /a/ task?
    r. Mean shimmer of the sung /a/ task?
    s. Mean jitter of the sung /a/ task?
    t. Mean HNR of the sung /a/ task?
    u. Mean F_0 of the Amazing Grace task?
    v. Mean P_0 of the Amazing Grace task?
    w. Mean dB SPL of the Amazing Grace task?
    x. Mean LTAS of the Amazing Grace task?
    y. Mean alpha ratio of the Amazing Grace task?
    z. Mean dB SPL 1-3 kHz of the Amazing Grace task?
    aa. Mean pitch strength of the Amazing Grace task?
    bb. Mean shimmer of the Amazing Grace task?
    cc. Mean jitter of the Amazing Grace task?

dd. Mean HNR of the Amazing Grace task?
ee. Mean F_0 of the Rainbow Passage task?
ff. Mean P_0 of the Rainbow Passage task?
gg. Mean dB SPL of the Rainbow Passage task?
hh. Mean LTAS of the Rainbow Passage task?
ii. Mean alpha ratio of the Rainbow Passage task?
jj. Mean dB SPL 1-3 kHz of the Rainbow Passage task?
kk. Mean pitch strength of the Rainbow Passage task?
ll. Mean shimmer of the Rainbow Passage task?
mm. Mean jitter of the Rainbow Passage task?
nn. Mean HNR of the Rainbow Passage task?

3. Is there a significant correlation between Dc acquired during three days of ambulatory monitoring and:
   a. Mean F_0 of the spoken /a/ task?
   b. Mean P_0 of the spoken /a/ task?
   c. Mean dB SPL of the spoken /a/ task?
   d. Mean LTAS of the spoken /a/ task?
   e. Mean alpha ratio of the spoken a/ task?
   f. Mean dB SPL 1-3 kHz of the spoken /a/ task?
   g. Mean pitch strength of the spoken /a/ task?
   h. Mean shimmer of the spoken /a/ task?
   i. Mean jitter of the spoken /a/ task?
   j. Mean HNR of the spoken /a/ task?
   k. Mean F_0 of the sung /a/ task?
   l. Mean P_0 of the sung /a/ task?
   m. Mean dB SPL of the sung /a/ task?
   n. Mean LTAS of the sung /a/ task?
   o. Mean alpha ratio of the sung /a/ task?
   p. Mean dB SPL 1-3 kHz of the sung /a/ task?
   q. Mean pitch strength of the sung /a/ task?
   r. Mean shimmer of the sung /a/ task?
   s. Mean jitter of the sung /a/ task?
   t. Mean HNR of the sung /a/ task?
   u. Mean F_0 of the Amazing Grace task?
   v. Mean P_0 of the Amazing Grace task?
   w. Mean dB SPL of the Amazing Grace task?
   x. Mean LTAS of the Amazing Grace task?
   y. Mean alpha ratio of the Amazing Grace task?
   z. Mean dB SPL 1-3 kHz of the Amazing Grace task?
   aa. Mean pitch strength of the Amazing Grace task?
   bb. Mean shimmer of the Amazing Grace task?
   cc. Mean jitter of the Amazing Grace task?
   dd. Mean HNR of the Amazing Grace task?
   ee. Mean F_0 of the Rainbow Passage task?
   ff. Mean P_0 of the Rainbow Passage task?
   gg. Mean dB SPL of the Rainbow Passage task?

hh. Mean LTAS of the Rainbow Passage task?
ii. Mean alpha ratio of the Rainbow Passage task?
jj. Mean dB SPL 1-3 kHz of the Rainbow Passage task?
kk. Mean pitch strength of the Rainbow Passage task?
ll. Mean shimmer of the Rainbow Passage task?
mm. Mean jitter of the Rainbow Passage task?
nn. Mean HNR of the Rainbow Passage task?

4. Is there a significant correlation between Dd acquired during three days of ambulatory monitoring and:
   a. Mean F_0 of the spoken /a/ task?
   b. Mean P_0 of the spoken /a/ task?
   c. Mean dB SPL of the spoken /a/ task?
   d. Mean LTAS of the spoken /a/ task?
   e. Mean alpha ratio of the spoken a/ task?
   f. Mean dB SPL 1-3 kHz of the spoken /a/ task?
   g. Mean pitch strength of the spoken /a/ task?
   h. Mean shimmer of the spoken /a/ task?
   i. Mean jitter of the spoken /a/ task?
   j. Mean HNR of the spoken /a/ task?
   k. Mean F_0 of the sung /a/ task?
   l. Mean P_0 of the sung /a/ task?
   m. Mean dB SPL of the sung /a/ task?
   n. Mean LTAS of the sung /a/ task?
   o. Mean alpha ratio of the sung /a/ task?
   p. Mean dB SPL 1-3 kHz of the sung /a/ task?
   q. Mean pitch strength of the sung /a/ task?
   r. Mean shimmer of the sung /a/ task?
   s. Mean jitter of the sung /a/ task?
   t. Mean HNR of the sung /a/ task?
   u. Mean F_0 of the Amazing Grace task?
   v. Mean P_0 of the Amazing Grace task?
   w. Mean dB SPL of the Amazing Grace task?
   x. Mean LTAS of the Amazing Grace task?
   y. Mean alpha ratio of the Amazing Grace task?
   z. Mean dB SPL 1-3 kHz of the Amazing Grace task?
   aa. Mean pitch strength of the Amazing Grace task?
   bb. Mean shimmer of the Amazing Grace task?
   cc. Mean jitter of the Amazing Grace task?
   dd. Mean HNR of the Amazing Grace task?
   ee. Mean F_0 of the Rainbow Passage task?
   ff. Mean P_0 of the Rainbow Passage task?
   gg. Mean dB SPL of the Rainbow Passage task?
   hh. Mean LTAS of the Rainbow Passage task?
   ii. Mean alpha ratio of the Rainbow Passage task?
   jj. Mean dB SPL 1-3 kHz of the Rainbow Passage task?
   kk. Mean pitch strength of the Rainbow Passage task?

ll. Mean shimmer of the Rainbow Passage task?
mm. Mean jitter of the Rainbow Passage task?
nn. Mean HNR of the Rainbow Passage task?

5. To what extent do bio-acoustic accelerometer voice source data acquired from participants in this study predict participants' acoustic source filter measures of voice quality?

A. Are there significant differences between bio-acoustic vocal source measurements acquired by the VoxLog accelerometer transducer and acoustic source/filter measurements acquired by the VoxLog acoustic transducer?
   1. Are there significant differences between measurements of F_0 acquired simultaneously by the two VoxLog transducers during all acquired vocal tasks measurements (*N = 526)*.
   2. Are there significant differences between measurements of P_0 acquired simultaneously by the two VoxLog transducers during all acquired vocal tasks measurements (*N = 526)*.
   3. Are there significant differences between measurements of dB SPL acquired simultaneously by the two VoxLog transducers during all acquired vocal tasks measurements (*N = 526)*.
   4. Are there significant differences between measurements of LTAS slope acquired simultaneously by the two VoxLog transducers during all acquired vocal tasks measurements (*N = 526)*.
   5. Are there significant differences between measurements of alpha ratio acquired simultaneously by the two VoxLog transducers during all acquired vocal tasks measurements (*N = 526)*.
   6. Are there significant differences between measurements of dB SPL 1-3 kHz acquired simultaneously by the two VoxLog transducers during all acquired vocal tasks measurements (*N = 526)*.
   7. Are there significant differences between measurements of pitch strength acquired simultaneously by the two VoxLog transducers during all acquired vocal tasks measurements (*N = 526)*.
   8. Are there significant differences between measurements of shimmer acquired simultaneously by the two VoxLog transducers during all acquired vocal tasks measurements (*N = 526)*.
   9. Are there significant differences between measurements of jitter acquired simultaneously by the two VoxLog transducers during all acquired vocal tasks measurements (*N = 526)*.

B. Are there significant differences between measurements of HNR acquired simultaneously by the two VoxLog transducers during all acquired vocal tasks measurements (*N = 526)*. When there are differences, can bio-acoustic vocal source measurements acquired by the VoxLog accelerometer transducer be used to predict acoustic source/filter measurements acquired by the VoxLog acoustic transducer?
   1. Based on the acquired vocal tasks acquired simultaneously from two transducers (*N = 526)*, what is the regression formula for predicting an acoustic reading of F_0 from an accelerometer reading of that measure.

2. Based on the acquired vocal tasks acquired simultaneously from two transducers (*N = 526)*, what is the regression formula for predicting an acoustic reading of P_0 from an accelerometer reading of that measure.
3. Based on the acquired vocal tasks acquired simultaneously from two transducers (*N = 526)*, what is the regression formula for predicting an acoustic reading of dB SPL from an accelerometer reading of that measure.
4. Based on the acquired vocal tasks acquired simultaneously from two transducers (*N = 526)*, what is the regression formula for predicting an acoustic reading of LTAS slope from an accelerometer reading of that measure.
5. Based on the acquired vocal tasks acquired simultaneously from two transducers (*N = 526)*, what is the regression formula for predicting an acoustic reading of alpha ratio from an accelerometer reading of that measure.
6. Based on the acquired vocal tasks acquired simultaneously from two transducers (*N = 526)*, what is the regression formula for predicting an acoustic reading of dB SPL 1-3 kHz from an accelerometer reading of that measure.
7. Based on the acquired vocal tasks acquired simultaneously from two transducers (*N = 526)*, what is the regression formula for predicting an acoustic reading of pitch strength from an accelerometer reading of that measure.
8. Based on the acquired vocal tasks acquired simultaneously from two transducers (*N = 526)*, what is the regression formula for predicting an acoustic reading of shimmer from an accelerometer reading of that measure.
9. Based on the acquired vocal tasks acquired simultaneously from two transducers (*N = 526)*, what is the regression formula for predicting an acoustic reading of jitter from an accelerometer reading of that measure.
10. Based on the acquired vocal tasks acquired simultaneously from two transducers (*N = 526)*, what is the regression formula for predicting an acoustic reading of HNR from an accelerometer reading of that measure.

Appendix G

Individual Participant Voicing Reports

Participant 2: Bass - Age 19

	Rec Hrs	Voice %	Dt (sec)	Dc	Dd	Fo	Po	dB SPL	PS	Alpha ratio	dB 1-3 kHz	LTAS slope	Jitt %	Shim %	HNR
Full Days															
Day 1	12.57	16.02	7246.83	1060.13	4477.17	139.92	152.68	71.52	30.30	-23.46	-54.78	-0.0070	3.28	12.26	11.58
Day 2	15.25	13.42	7366.92	1024.13	4362.15	135.99	142.04	70.84	29.44	0.00	-53.46	-0.0071	3.05	11.07	12.17
Day 3	12.88	11.37	5274.57	711.16	2948.09	134.51	135.21	68.04	27.53	-21.20	-50.04	-0.0061	3.31	11.78	9.94
MEAN	13.57	13.89	6629.44	931.81	3929.14	137.09	144.33	70.40	29.29	-13.98	-53.11	-0.0068	3.20	11.69	11.40
MEAN per hr			488.66	68.68	289.62										
TOTALS	40.70		19888.32	2795.42	11787.41										
Activities															
Non-Sing	Rec Hrs	Voice %	Dt (sec)	Dc	Dd	Fo	Po	dB SPL	PS	Alpha ratio	dB 1-3 kHz	LTAS slope	Jitt %	Shim %	HNR
Day 1	10.22	8.50	3127.14	451.80	1877.73	140.17	148.85	70.25	28.99	-22.47	-51.46	-0.0068	3.55	11.77	10.37
Day 2	14.18	10.31	5264.28	717.02	3023.99	132.65	139.80	70.16	28.57	0.00	-52.52	-0.0070	3.37	11.53	10.63
Day 3	12.47	10.14	4551.87	600.57	2445.30	131.80	132.11	67.08	25.68	-20.68	-49.30	-0.0059	3.46	12.15	9.06
MEAN	12.29	9.81	4314.43	589.80	2449.01	134.09	139.56	69.10	27.58	-13.00	-51.06	-0.0066	3.44	11.82	9.98
MEAN per hr			351.08	47.99	199.29										
TOTALS	36.87		12943.3	1769.39	7347.03										
Solo Singing															
Day 1	0.35	50.99	642.42	87.42	403.35	138.30	134.03	73.36	38.63	-25.48	-61.39	-0.0071	1.97	6.66	19.87
Day 2	0.77	51.83	1430.46	222.01	982.98	153.95	156.36	73.55	31.37	0.00	-54.10	-0.0076	2.22	8.38	17.25
Day 3	0.33	49.45	593.34	92.14	424.16	156.67	154.01	74.59	40.69	-24.71	-54.30	-0.0077	2.49	10.51	14.61
MEAN	0.48	51.09	888.74	133.85	603.49	150.80	150.44	73.73	35.19	-11.61	-55.89	-0.0075	2.22	8.44	17.29
MEAN per hr			1838.77	276.94	1248.61										
TOTALS	1.45		2666.22	401.56	1810.48										
Choral Singing															
Day 1	1.92	47.86	3302.37	494.22	2081.72	139.29	160.12	72.29	28.95	-23.91	-56.49	-0.0072	3.40	14.27	10.43
Day 2	0.20	67.96	489.30	57.18	227.01	116.13	117.65	68.78	30.45	0.00	-59.60	-0.0065	2.63	15.96	10.44
Day 3															
MEAN	1.06	50.45	1895.84	275.70	1154.37	136.18	154.86	71.84	29.15	-20.71	-56.91	-0.0071	3.30	14.50	10.43
MEAN per hr			1791.34	260.50	1090.74										
TOTALS	2.12		3791.67	551.40	2308.73										

Note: "Activities" data do not include vocal dose information from the vocal tasks that were completed each day, while the "Full Days" data do, so the "Activities" dose totals will not equal the "Full Days" totals when added together.

Participant 3: Tenor - Age 18

Full Days	Rec Hrs	Voice %	Dt (sec)	Dc	Dd	Fo	Po	dB SPL	PS	Alpha ratio	dB 1- 3 kHz	LTAS slope	Jitter %	Shimm %	HNR
Day 1	16.17	13.20	7682.13	1581.69	9149.62	202.83	209.38	82.99	32.86	-26.99	-58.77	-0.0069	3.53	13.26	11.86
Day 2	14.37	16.31	8436.36	1911.47	12027.45	214.16	240.64	86.32	36.53	-27.93	-58.80	-0.0076	2.85	11.23	14.60
Day 3	17.82	15.67	10049.13	2044.80	13777.89	201.94	205.03	86.55	34.56	-28.34	-58.65	-0.0079	3.00	12.34	12.48
MEAN	16.12	15.15	8722,54	1845.99	11651.65	206.23	217.49	85.43	34.70	-27.80	-58.74	-0.0075	3.11	12.25	12.99
MEAN per hr			541.21	114.54	722.96										
TOTALS	48.35		26167,62	5537.96	34954.96										

Activities

Non-Sing	Rec Hrs	Voice %	Dt (sec)	Dc	Dd	Fo	Po	dB SPL	PS	Alpha ratio	dB 1- 3 kHz	LTAS slope	Jitter %	Shimm %	HNR
Day 1	14.52	11.51	6014.37	1174.38	6505.51	193.31	197.59	81.60	31.31	-26.96	-59.49	-0.0065	3.86	13.88	10.99
Day 2	12.38	14.72	6561.69	1459.92	8953.69	207.73	239.89	85.57	35.10	-28.11	-59.24	-0.0074	3.15	12.02	13.67
Day 3	14.83	10.88	5808.99	1083.08	7144.01	186.69	186.20	85.06	31.38	-28.32	-59.59	-0.0073	3.57	13.79	10.79
MEAN	13.91	12.46	6128.35	1239.13	7534.40	196.54	208.64	84.11	84.11	-27.79	-59.43	-0.0071	3.51	13.18	11.90
MEAN per hour			440.54	89.07	541.61										
TOTALS	41.73		18385.05	3717.38	22603.21										
Solo Singing															
Day 1															
Day 2															
Day 3	1.53	44.12	2435.34	533.82	3775.62	214.82	223.26	88.84	38.01	-29.68	-57.00	-0.0091	2.27	10.38	14.59
MEAN	1.53	44.12	2435.34	533.82	3775.62	214.82	223.26	88.84	38.01	-29.68	-57.00	-0.0091	2.27	10.38	14.59
MEAN per hour			1588.27	348.14	2462.36										
TOTALS	1.53		2435.34	533.82	3775.62										
Choral Singing															
Day 1	1.55	26.01	1451.58	364.60	2410.10	247.71	254.46	88.94	38.14	-26.63	-55.26	-0.0089	2.43	11.43	14.64
Day 2	1.88	24.85	1684.89	412.80	2849.98	242.65	247.31	89.59	41.90	-27.12	-56.77	-0.0087	1.75	8.26	18.33
Day 3	1.38	33.87	1686.66	404.32	2725.89	237.76	241.68	88.69	40.42	-26.61	-57.63	-0.0087	2.10	10.24	15.28
MEAN	1.61	28.35	1607.71	393.91	2661.99	242.42	247.55	89.08	40.27	-26.80	-56.63	-0.0087	2.07	9.90	16.16
MEAN per hour			1001.34	245.34	1657.99										
TOTALS	4.82		4823.13	1181.72	7985.97										

Note: "Activities" data do not include vocal dose information from the vocal tasks that were completed each day, while the "Full Days" data do, so the "Activities" dose totals will not equal the "Full Days" totals when added together.

Participant 4: Baritone – Age 19

Full Days

	Rec Hrs	Voice %	Dt (sec)	Dc	Dd	Fo	Po	dB SPL	PS	Alpha ratio	dB 1-3 kHz	LTAS slope	Jitter %	Shim %	HNR
Day 1	13.70	15.68	7733.88	1088.00	5259.39	141.71	139.67	74.50	29.14	-26.66	-59.86	-0.0070	3.40	14.35	10.75
Day 2	11.42	13.97	5742.90	811.01	4258.09	141.78	140.63	76.80	29.86	-23.11	-57.92	-0.0061	3.45	13.46	11.49
Day 3	16.10	12.98	7521.03	1057.24	6216.86	140.05	141.09	79.33	31.33	-22.71	-56.68	-0.0064	3.20	12.83	12.17
MEAN	13.74	14.25	6999.27	985.41	5244.78	141.14	140.44	76.86	30.12	-24.27	-58.19	-0.0066	3.34	13.56	11.46
MEAN per hr			509.45	71.72	381.75										
TOTALS	41.22		20997.81	2956.24	15734.34										

Activities	Rec Hrs	Voice %	Dt (sec)	Dc	Dd	Fo	Po	dB SPL	PS	Alpha ratio	dB 1-3 kHz	LTAS slope	Jitter %	Shim %	HNR
Non-Sing															
Day 1	11.82	12.90	5489.34	671.58	3134.84	124.27	120.41	72.76	26.77	-26.42	-60.69	-0.0065	3.91	15.57	9.49
Day 2	10.07	9.66	3500.97	446.42	2528.80	129.20	125.71	77.55	28.42	-23.03	-58.32	-0.0060	4.10	13.57	10.53
Day 3	14.67	9.38	4952.76	637.58	3754.46	130.82	126.62	78.56	27.47	-23.01	-57.66	-0.0061	3.92	14.41	10.15
MEAN	12.18	10.84	4647.69	585.20	3139.37	127.85	123.93	76.02	27.44	-24.34	-59.01	-0.0062	3.96	14.65	9.99
MEAN per hour			381.48	48.03	257.68										
TOTALS	36.55		13943.07	1755.59	9418.10										
Solo Singing															
Day 1	0.42	47.67	715.08	115.21	661.69	158.61	163.32	79.89	35.65	-28.20	-57.06	-0.0093	1.69	10.1	14.78
Day 2															
Day 3	0.50	53.91	970.35	162.49	970.53	161.11	173.37	81.49	38.25	-22.01	-52.25	-0.0075	2.11	10.58	14.58
MEAN	0.46	51.26	842.72	138.85	816.11	160.07	169.04	80.81	37.17	-24.59	-54.26	-0.0082	1.93	10.39	14.66
MEAN per hour			1838.65	302.95	1780.61										
TOTALS	0.92		1685.43	277.71	1632.22										
Choral Singing															
Day 1	1.30	28.06	1313.25	269.06	1304.00	206.55	203.28	78.69	34.13	-26.63	-57.72	-0.0080	2.39	12.15	13.02
Day 2	0.88	47.88	1522.62	251.45	1298.84	166.08	164.26	78.24	36.04	-23.61	-57.87	-0.0069	2.15	11.74	14.41
Day 3	0.83	47.81	1434.24	236.09	1356.95	160.64	168.23	80.39	39.57	-21.57	-55.82	-0.0067	1.53	9.38	17.06
MEAN	1.01	41.76	1423.37	252.20	1319.93	176.87	177.48	79.10	36.61	-23.88	-57.14	-0.0072	2.02	11.09	14.85
MEAN per hour			1415.51	250.81	1312.64										
TOTALS	3.02		4270.11	756.60	3959.79										

Note: "Activities" data do not include vocal dose information from the vocal tasks that were completed each day, while the "Full Days" data do, so the "Activities" dose totals will not equal the "Full Days" totals when added together.

Participant 5: Baritone – Age 19

Full Days	Rec Hrs	Voice %	Dt (sec)	Dc	Dd	Fo	Po	dB SPL	PS	Alpha ratio	dB 1-3 kHz	LTAS slope	Jitter %	Shim m %	HNR
Day 1	14.72	12.07	6394.41	1176.06	3890.92	187.34	179.87	68.84	29.99	-24.17	-57.02	-0.0065	3.14	14.58	10.43
Day 2	13.68	10.91	5373.57	914.58	3389.49	172.08	168.01	70.63	32.30	-25.25	-58.12	-0.0069	3.26	13.20	11.53
Day 3	9.20	10.50	3476.22	573.14	2219.69	166.97	162.63	71.15	33.27	-25.30	-55.97	-0.0073	2.98	12.92	11.77
MEAN	12.53	11.29	5081.40	887.93	3166.70	177.17	171.64	70.01	31.57	-24.82	-57.16	-0.0068	3.14	13.71	11.13
MEAN per hr			405.43	70.85	252.66										
TOTALS	37.60		15244.20	2663.78	9500.11										

Activities	Rec Hrs	Voice %	Dt (sec)	Dc	Dd	Fo	Po	dB SPL	PS	Alpha ratio	dB 1-3 kHz	LTAS slope	Jitter %	Shim m %	HNR
Non-Sing															
Day 1	12.72	9.40	4304.40	813.08	2580.27	194.19	182.38	68.29	27.11	-23.95	-57.32	-0.0061	3.32	15.34	9.52
Day 2	12.73	8.23	3773.58	618.71	2325.29	165.77	161.87	70.65	30.70	-25.35	-57.79	-0.0068	3.67	13.22	10.97
Day 3	7.57	5.11	1390.62	199.82	806.02	147.95	138.97	70.98	28.11	-24.68	-56.61	-0.0066	4.24	14.19	9.78
MEAN	11.01	8.30	3156.20	543.87	1903.86	176.39	167.50	69.63	28.67	-24.61	-57.40	-0.0065	3.59	14.34	10.13
MEAN per hour			286.78	49.42	172.99										
TOTALS	33.02		9468.60	1631.61	5711.59										
Solo Singing															
Day 1	0.53	41.95	805.41	146.46	571.07	177.33	186.61	72.17	35.30	-25.89	-55.56	-0.0079	3.17	15.21	9.80
Day 2															
Day 3	0.27	58.98	566.16	112.51	494.45	195.55	201.81	76.23	42.57	-25.60	-52.13	-0.0089	1.99	11.57	12.53
MEAN	0.40	48.98	685.79	129.49	532.76	184.67	193.04	73.84	38.23	-25.77	-54.18	-0.0083	2.69	13.74	10.90
MEAN per hour			1714.46	323.72	1331.91										
TOTALS	0.80		1371.57	258.98	1065.52										
Choral Singing															
Day 1	1.38	22.86	1138.41	196.42	664.03	173.15	171.84	68.57	36.52	-23.57	-56.69	-0.0066	2.58	11.79	13.75
Day 2	0.85	47.05	1439.88	273.00	971.85	191.08	187.79	70.57	36.57	-24.93	-59.13	-0.0070	2.38	13.45	12.40
Day 3	1.27	29.97	1366.62	238.42	830.04	177.49	171.18	69.24	33.90	-25.66	-56.69	-0.0074	2.30	12.54	12.86
MEAN	1.17	34.15	1314.97	235.95	821.98	181.35	177.23	69.53	35.65	-24.79	-57.61	-0.0070	2.41	12.67	12.95
MEAN per hour			1127.12	202.24	704.55										
TOTALS	3.50		3944.91	707.84	2465.93										

Note: "Activities" data do not include vocal dose information from the vocal tasks that were completed each day, while the "Full Days" data do include these data, so the "Activities" dose totals will not equal the "Full Days" totals when added together.

Participant 6: Baritone – Age 19

Full Days	**Rec Hrs**	Voice %	Dt (sec)	Dc	Dd	Fo	Po	dB SPL	PS	Alpha ratio	dB 1-3 kHz	LTAS slope	Jitter %	Shim %	HNR
Day 1	14.23	7.89	4042.68	602.54	2196.36	143.47	156.85	68.15	35.85	-22.88	-59.57	-0.0063	3.73	13.18	12.58
Day 2	13.90	6.21	3109.77	395.63	1308.44	128.99	124.42	65.21	29.04	-22.09	-57.99	-0.0060	4.90	15.07	9.94
Day 3	14.55	11.65	6102.12	809.94	2972.33	129.35	138.12	67.27	31.21	-21.26	-58.16	-0.0060	5.10	15.05	10.14
MEAN	14.23	9.23	4418.19	602.70	2159.05	133.42	140.99	67.05	32.06	-21.94	-58.53	-0.0061	4.65	14.51	10.81
MEAN per hr			310.53	42.36	151.75										
TOTALS	42.68		13254.57	1808.11	6477.14										

Activities	**Rec Hrs**	Voice %	Dt (sec)	Dc	Dd	Fo	Po	dB SPL	PS	Alpha ratio	dB 1-3 kHz	LTAS slope	Jitter %	Shim %	HNR
Non-Sing															
Day 1	13.28	5.34	2552.91	337.43	1140.61	127.36	139.89	65.67	29.63	-20.73	-58.73	-0.0054	4.90	15.80	9.81
Day 2	13.78	5.99	2970.39	375.23	1244.34	128.16	123.42	65.22	28.25	-21.92	-57.89	-0.0060	5.00	15.29	9.62
Day 3	13.15	8.97	4246.26	494.21	1676.93	115.53	117.98	64.91	25.18	-18.89	-58.39	-0.0050	6.08	17.07	8.42
MEAN	13.41	7.11	3256.52	402.29	1353.96	122.29	125.66	65.20	27.22	-20.26	-58.33	-0.0054	5.46	16.22	9.13
MEAN per hr			242.92	30.01	101.00										
TOTALS	40.22		9769.56	1206.87	4061.88										
Solo Singing															
Day 1															
Day 2															
Day 3	0.52	39.24	729.78	139.55	599.52	187.79	195.04	74.99	50.99	-27.73	-55.16	-0.0094	2.13	8.93	15.15
MEAN	0.52	39.24	729.78	139.55	599.52	187.79	195.04	74.99	50.99	-27.73	-55.16	0.0094	2.13	8.9	15.15
MEAN per hr			1412.48	270.10	1160.35										
TOTALS	0.52		729.78	139.55	599.52										
Choral Singing															
Day 1	0.85	43.98	1345.89	243.78	992.92	178.97	183.44	73.31	49.90	-27.36	-61.19	-0.0085	1.44	8.28	17.71
Day 2															
Day 3	0.78	33.87	955.14	151.99	614.36	158.67	159.65	71.99	46.15	-28.09	-58.80	-0.0090	2.13	9.93	14.90
MEAN	0.82	39.79	1150.52	197.89	803.64	170.44	173.69	72.76	48.33	-27.67	-60.19	-0.0087	1.73	8.97	16.53
MEAN per hr			1408.79	242.31	984.04										
TOTALS	1.63		2301.03	395.78	1607.27										

Note: "Activities" data do not include vocal dose information from the vocal tasks that were completed each day, while the "Full Days" data do include these data, so the "Activities" dose totals will not equal the "Full Days" totals when added together.

Participant 7: Soprano – Age 19

Full Days	Rec Hrs	Voice %	Dt (sec)	Dc	Dd	Fo	Po	dB SPL	PS	Alpha ratio	dB 1-3 kHz	LTAS slope	Jitter %	Shim %	HNR
Day 1	12.77	9.21	4234.00	1248.37	3754.75	296.47	292.93	77.31	24.74	-20.31	-50.14	-0.0062	3.19	16.05	9.56
Day 2	13.00	6.17	2887.23	738.44	2453.91	266.99	244.01	78.40	25.81	-20.11	-51.12	-0.0060	3.92	15.38	9.48
Day 3	13.20	7.76	3685.67	1073.66	3403.23	291.03	291.61	78.69	23.87	-18.59	-49.70	-0.0060	3.20	16.04	9.66
MEAN	12.99	7.87	3602.30	1020.15	3203.96	286.45	278.93	78.08	24.74	-19.67	-50.26	-0.0061	3.40	15.86	9.57
MEAN per hr			277.34	78.54	246.67										
TOTALS	38.97		10806.90	3060.46	9611.88										

Activities	Rec Hrs	Voice %	Dt (sec)	Dc	Dd	Fo	Po	dB SPL	PS	Alpha ratio	dB 1-3 kHz	LTAS slope	Jitter %	Shim %	HNR
Non-Sing															
Day 1	11.33	4.87	1986.18	528.84	1852.61	277.43	253.49	79.20	27.04	-20.81	-50.60	-0.0061	3.28	14.30	10.84
Day 2	12.90	5.90	2740.88	698.03	2338.33	266.27	242.37	78.54	26.36	-20.36	-50.86	-0.0061	3.86	15.22	9.64
Day 3	12.28	4.96	2192.68	582.18	1902.50	279.38	250.71	78.23	24.20	-17.64	-49.62	-0.0052	3.72	16.21	8.67
MEAN	12.17	5.31	2306.58	603.01	2031.15	273.67	248.14	78.63	25.88	-19.63	-50.40	-0.0058	3.65	15.26	9.69
MEAN per hour			189.50	49.54	166.87										
TOTALS	36.52		6919.74	1809.04	6093.44										
Solo Singing															
Day1	0.50	37.96	683.27	251.73	674.27	373.38	363.23	78.10	26.85	-22.78	-50.86	-0.0073	2.98	14.29	11.15
Day2															
Day3															
MEAN	0.50	37.96	683.27	251.73	674.27	373.38	363.23	78.10	26.85	-22.78	-50.86	-0.0073	2.98	14.29	11.15
MEAN per hour			1366.54	503.47	1348.55										
TOTALS	0.50		683.27	251.73	674.27										
Choral Singing															
Day1	0.83	46.81	1407.01	425.15	1108.46	290.45	317.53	74.53	19.20	-18.59	-48.75	-0.0059	3.37	19.92	6.35
Day2															
Day3	0.85	46.19	1413.47	470.00	1438.54	308.84	361.56	79.58	23.07	-19.81	-49.59	-0.0072	2.52	15.99	10.93
MEAN	0.84	46.50	1410.24	447.57	1273.50	299.53	340.01	77.06	21.11	-19.19	-49.16	-0.0065	2.95	17.98	8.61
MEAN per hour			1675.53	531.77	1513.07										
TOTALS	1.68		2820.47	895.15	2547.00										

Note: “Activities” data do not include vocal dose information from the vocal tasks that were completed each day, while the “Full Days” data do include these data, so the “Activities” dose totals will not equal the “Full Days” totals when added together.

Participant 8: Soprano – Age 18

Full Days	Rec Hrs	Voice %	Dt (sec)	Dc	Dd	Fo	Po	dB SPL	PS	Alpha ratio	dB 1-3 kHz	LTAS slope	Jitter %	Shim %	HNR
Day 1	14.62	8.38	4411.35	1450.58	3428.28	322.34	337.20	72.87	30.09	-23.21	-57.69	-0.0055	3.19	13.68	12.03
Day 2	12.52	7.98	3595.32	1219.38	2879.33	338.67	339.73	73.37	32.43	-24.68	-58.19	-0.0061	2.99	12.19	13.94
Day 3	14.50	9.01	4702.59	1617.03	3891.95	339.27	349.39	73.90	31.14	-24.52	-57.88	-0.0061	3.29	13.04	13.02
MEAN	13.88	8.50	4236.42	1429.00	3399.85	333.37	342.48	73.40	31.16	-24.12	-57.91	-0.0059	3.17	13.01	12.95
MEAN per hr			305.27	102.97	244.99										
TOTALS	41.63		12709.26	4286.99	10199.56										

Activities	Rec Hrs	Voice %	Dt (sec)	Dc	Dd	Fo	Po	dB SPL	PS	Alpha ratio	dB 1-3 kHz	LTAS slope	Jitter %	Shim %	HNR
Non-Sing															
Day 1	13.67	5.89	2900.25	832.25	1921.33	292.99	278.38	70.81	28.11	-22.22	-55.94	-0.0050	3.58	14.19	10.60
Day 2	11.78	5.94	2520.24	773.85	1773.22	311.21	301.89	71.65	29.46	-23.85	-56.32	-0.0055	3.40	13.16	11.99
Day 3	12.88	5.76	2673.42	806.43	1913.89	306.00	296.00	71.97	27.39	-22.94	-55.67	-0.0054	3.80	14.38	10.60
MEAN	12.78	5.87	2697.97	804.18	1869.48	302.75	291.88	71.45	28.28	-22.95	-55.97	-0.0053	3.60	13.94	11.02
MEAN per hour			211.15	62.94	146.31										
TOTALS	38.33		8093.91	2412.53	5608.45										
Solo Singing															
Day1															
Day2	0.08	48.09	144.27	49.86	106.39	331.33	362.89	71.55	29.28	-27.09	-58.91	-0.0070	3.64	12.26	16.63
Day3	0.70	34.99	881.79	319.75	740.17	354.28	372.45	74.07	34.60	-28.28	-59.73	-0.0072	3.77	13.25	12.60
MEAN	0.39	36.83	513.03	184.80	423.28	351.02	371.12	73.71	33.84	-28.11	-59.61	-0.0072	3.75	13.11	13.17
MEAN per hour			1309.86	471.84	1080.72										
TOTALS	0.78		1026.06	369.61	846.56										
Choral Singing															
Day1	0.83	44.37	1330.95	561.62	1391.83	398.46	445.72	77.86	33.96	-25.77	-61.88	-0.0068	2.56	13.46	14.25
Day2	0.58	38.70	812.70	356.35	920.50	435.90	441.04	79.57	42.13	-26.92	-64.26	-0.0078	1.85	9.55	19.27
Day3	0.83	34.24	1027.14	451.79	1158.80	424.18	455.80	79.29	38.01	-25.47	-62.38	-0.0073	1.64	9.35	19.78
MEAN	0.75	39.63	1056.93	456.59	1157.04	416.36	447.76	78.76	37.36	-25.97	-62.65	-0.0072	2.08	11.13	17.32
MEAN per hour			1409.24	608.78	1542.72										
TOTALS	2.25		3170.79	1369.76	3471.13										

Note: “Activities” data do not include vocal dose information from the vocal tasks that were completed each day, while the “Full Days” data do include these data, so the “Activities” dose totals will not equal the “Full Days” totals when added together.

Participant 9: Soprano – Age 19

Full Days	Rec Hrs	Voice %	Dt (sec)	Dc	Dd	Fo	Po	dB SPL	PS	Alpha ratio	dB 1-3 kHz	LTAS slope	Jitter %	Shim %	HNR
Day 1	12.13	18.23	7962.27	2414.31	8638.20	303.30	303.14	81.77	38.05	-20.97	-51.90	-0.0064	2.50	11.19	15.39
Day 2	10.48	18.29	6900.96	2052.30	8036.27	297.16	297.63	83.86	39.18	-20.77	-51.43	-0.0063	2.36	9.94	16.20
Day 3	15.73	11.40	6456.99	1688.38	6004.68	266.11	256.42	80.32	35.77	-21.81	-52.62	-0.0056	2.91	11.62	13.61
MEAN	12.78	16.18	7106.74	2051.66	7559.72	289.82	287.52	82.00	37.70	-21.16	-51.97	-0.0061	2.58	10.93	15.10
MEAN per hr			555.94	160.50	591.37										
TOTALS	38.35		21320.22	6154.99	22679.15										

Activities	Rec Hrs	Voice %	Dt (sec)	Dc	Dd	Fo	Po	dB SPL	PS	Alpha ratio	dB 1-3 kHz	LTAS slope	Jitter %	Shim %	HNR
Non-Sing															
Day 1	10.27	13.80	5100.81	1370.32	4802.63	272.17	264.98	80.20	35.83	-20.55	-50.81	-0.0060	2.76	10.95	14.15
Day 2	8.68	14.13	4417.89	1169.15	4612.18	266.45	262.84	82.64	37.26	-20.59	-49.74	-0.0061	2.44	10.05	14.92
Day 3	15.10	10.18	5533.20	1379.35	4932.38	255.51	242.47	79.99	35.61	-21.21	-51.99	-0.0054	2.83	11.70	13.47
MEAN	11.35	12.57	5017.30	1306.28	4782.40	264.27	256.25	80.84	36.16	-20.81	-50.95	-0.0058	2.69	10.98	14.12
MEAN per hour			442.05	115.09	421.36										
TOTALS	34.05		15051.90	3918.83	14347.19										
Solo Singing															
Day1	0.90	49.90	1616.64	623.16	2535.45	384.92	386.02	88.14	49.34	-23.41	-54.79	-0.0076	1.57	8.22	21.59
Day2	0.82	36.25	1065.81	325.81	1565.24	305.37	306.02	88.96	47.31	-22.77	-53.47	-0.0071	1.84	6.56	20.89
Day3	0.52	37.97	706.20	254.56	899.34	355.62	365.61	83.93	36.12	-25.94	-55.66	-0.0077	3.79	12.32	13.06
MEAN	0.74	43.12	1129.55	401.18	1666.68	353.62	356.75	87.52	45.89	-23.74	-54.56	-0.0074	2.12	8.57	19.55
MEAN per hour			1517.31	538.90	2238.82										
TOTALS	2.23		3388.65	1203.53	5000.03										
Choral Singing															
Day1	0.87	34.50	1076.52	375.65	1152.44	336.28	361.94	80.13	31.34	-19.20	-52.05	-0.0067	2.74	16.85	11.77
Day2	0.88	37.90	1205.25	505.52	1651.98	408.82	430.56	84.13	37.65	-19.16	-54.96	-0.0065	2.77	13.04	15.56
Day3															
MEAN	0.88	36.30	1140.89	440.58	1402.21	374.80	397.98	82.24	34.69	-19.18	-53.60	-0.0066	2.76	14.82	13.78
MEAN per hour			1303.87	503.52	1602.52										
TOTALS	1.75		2281.77	881.17	2804.41										

Note: “Activities” data do not include vocal dose information from the vocal tasks that were completed each day, while the “Full Days” data do include these data, so the “Activities” dose totals will not equal the “Full Days” totals when added together.

Participant 11: Soprano – Age 21

Full Days	Rec Hrs	Voice %	Dt (sec)	Dc	Dd	Fo	Po	dB SPL	PS	Alpha ratio	dB 1-3 kHz	LTAS slope	Jitter %	Shim %	HNR
Day 1	16.83	10.58	6413.34	2095.68	5850.74	344.98	294.37	77.53	24.44	-21.12	-53.48	-0.0045	4.93	17.47	6.96
Day 2	13.77	9.32	4619.40	1508.43	3785.48	321.03	336.06	75.19	26.20	-21.08	-55.43	-0.0044	3.49	14.16	10.28
Day 3	13.35	6.59	3167.91	1163.77	2791.38	361.92	375.54	75.60	28.34	-20.41	-56.49	-0.0043	3.35	12.47	11.67
MEAN	14.65	9.28	4733.55	1589.30	4142.53	340.75	327.30	76.34	25.84	-20.95	-54.76	-0.0044	4.12	15.32	9.05
MEAN per hr			323.11	108.48	282.77										
TOTALS	43.95		14200.65	4767.89	12427.60										

Activities	Rec Hrs	Voice %	Dt (sec)	Dc	Dd	Fo	Po	dB SPL	PS	Alpha ratio	dB 1-3 kHz	LTAS slope	Jitter %	Shim %	HNR
Non-Sing															
Day 1	15.83	9.23	5260.38	1682.99	4761.36	343.91	274.24	77.64	23.81	-20.96	-52.97	-0.0045	5.06	17.61	6.45
Day 2	12.57	6.93	3135.96	878.45	2388.80	281.37	277.64	74.91	22.53	-20.97	-54.99	-0.0043	3.96	16.42	7.55
Day 3	12.27	3.06	1351.74	397.74	1057.03	300.71	280.65	74.83	24.14	-18.97	-55.77	-0.0038	3.61	13.51	9.61
MEAN	13.56	7.63	3249.36	986.40	2735.73	317.55	276.17	76.37	23.44	-20.68	-54.02	-0.0044	4.50	16.64	7.26
MEAN per hour			239.71	72.77	201.82										
TOTALS	40.67		9748.08	2959.19	8207.20										
Solo Singing															
Day1															
Day2	1.08	33.72	1315.02	573.55	1263.11	431.38	442.34	76.05	35.40	-21.69	-56.37	-0.0048	2.49	8.65	16.78
Day3	0.53	61.15	1173.99	531.61	1178.22	454.18	451.35	76.80	35.24	-22.45	-57.36	-0.0053	2.72	9.66	15.12
MEAN	0.81	46.65	1244.51	552.58	1220.67	441.68	446.80	76.41	35.33	-22.03	-56.82	-0.0050	2.59	9.11	16.03
MEAN per hour			1539.59	683.61	1510.10										
TOTALS	1.62		2489.01	1105.16	2441.34										
Choral Singing															
Day1	0.87	31.27	975.60	355.69	944.27	356.27	375.78	77.40	26.17	-22.23	-55.98	-0.0041	4.81	17.90	8.07
Day2															
Day3	0.43	31.08	484.83	182.48	434.14	370.81	384.01	75.56	26.04	-21.64	-57.00	-0.0044	4.53	16.46	9.19
MEAN	0.65	31.21	730.22	269.09	689.20	361.12	378.50	76.79	26.12	-22.03	-56.32	-0.0042	4.72	17.42	8.45
MEAN per hour			1123.41	413.98	1060.32										
TOTALS	1.30		1460.43	538.18	1378.41										

Note: “Activities” data do not include vocal dose information from the vocal tasks that were completed each day, while the “Full Days” data do include these data, so the “Activities” dose totals will not equal the “Full Days” totals when added together.

Participant 13: Baritone – Age 18

Full Days

	Rec Hrs	Voice %	Dt (sec)	Dc	Dd	Fo	Po	dB SPL	PS	Alpha ratio	dB 1-3 kHz	LTAS slope	Jitter %	Shim %	HNR
Day 1	16.57	14.47	8630.52	1392.29	5479.47	163.35	159.18	71.54	-23.38	27.58	-57.89	-0.0053	3.44	15.83	9.16
Day 2	13.78	8.33	4131.84	570.50	2269.39	141.51	134.23	70.31	-21.78	28.31	-57.76	-0.0048	3.89	14.87	9.82
Day 3	14.12	9.26	4703.58	782.50	3144.13	167.03	165.69	72.44	-23.42	29.21	-58.75	-0.0051	3.18	13.98	10.72
MEAN	14.82	11.61	5821.98	915.10	3630.99	159.02	155.24	71.49	-23.00	28.19	-58.08	-0.0051	3.4	15.11	2.82
MEAN per hr			392.79	61.74	244.97										
TOTALS	44.47		17465.94	2745.29	10892.98										

Activities	Rec Hrs	Voice %	Dt (sec)	Dc	Dd	Fo	Po	dB SPL	PS	Alpha ratio	dB 1-3 kHz	LTAS slope	Jitter %	Shim %	HNR
Non-Sing															
Day 1	15.70	16.21	5583.45	1069.58	4372.70	157.12	154.48	71.91	-23.18	28.03	-58.15	-0.0052	3.49	15.50	9.52
Day 2	12.73	6.05	2772.45	357.48	1489.82	132.74	124.67	70.75	-21.46	27.26	-57.42	-0.0047	4.12	15.04	9.42
Day 3	12.77	5.17	2376.90	383.18	1559.77	160.52	161.90	72.54	-22.48	28.58	-58.32	-0.0049	3.84	14.61	9.62
MEAN	13.73	11.14	3577.60	603.42	2474.10	151.95	149.36	71.75	-22.63	27.95	-58.01	-0.0050	3.71	15.22	1.86
MEAN per hour			260.50	43.94	180.15										
TOTALS	41.20		10732.80	1810.25	7422.29										
Solo Singing															
Day 1															
Day 2															
Day 3	0.50	44.71	804.75	136.32	570.81	166.96	171.76	73.24	-26.09	30.87	-57.96	-0.0061	2.45	13.11	12.10
MEAN	0.50	44.71	804.75	136.32	570.81	166.96	171.76	73.24	-26.09	30.87	-57.96	-0.0061	2.45	13.11	12.10
MEAN per hour			1609.50	272.64	1141.61										
TOTALS	0.50		804.75	136.32	570.81										
Choral Singing															
Day 1	0.75	57.54	1553.58	290.00	973.88	190.53	182.15	69.58	-24.25	25.10	-56.81	-0.0057	3.50	17.65	7.03
Day 2	0.95	34.66	1185.21	186.51	687.60	160.57	153.80	69.64	-22.69	29.39	-58.46	-0.0049	3.78	14.79	9.86
Day 3	0.75	51.94	1402.35	244.20	938.78	178.41	169.57	71.89	-23.61	28.61	-59.94	-0.0050	2.66	14.02	11.07
MEAN	0.82	49.09	1380.38	240.24	866.76	177.95	169.66	70.38	-23.59	27.49	-58.32	-0.0053	3.30	15.63	3.67
MEAN per hour			1690.26	294.16	1061.33										
TOTALS	2.45		4141.14	720.70	2600.26										

Note: “Activities” data do not include vocal dose information from the vocal tasks that were completed each day, while the “Full Days” data do include these data, so the “Activities” dose totals will not equal the “Full Days” totals when added together.

Participant 15: Baritone – Age 22

Full Days	Rec Hrs	Voice %	Dt (sec)	Dc	Dd	Fo	Po	dB SPL	PS	Alpha ratio	dB 1-3 kHz	LTAS slope	Jitter %	Shim %	HNR
Day 1	16.13	14.17	8227.65	1313.05	6850.38	162.29	156.77	78.03	32.36	-25.94	-58.49	-0.0060	3.43	12.91	11.13
Day 2	15.13	12.87	7011.45	1186.55	5840.10	170.97	167.29	77.13	33.37	-24.77	-58.01	-0.0059	3.55	13.33	11.38
Day 3	14.10	12.11	6119.10	950.16	5409.74	161.12	149.46	79.57	29.33	-25.02	-57.71	-0.0060	3.82	14.62	9.59
MEAN	15.12	13.15	7119.40	1149.92	6033.41	164.71	157.97	78.19	31.79	-25.29	-58.11	-0.0060	3.58	13.55	10.76
MEAN per hr			470.79	76.04	398.98										
TOTALS	45.37		21358.20	3449.76	18100.22										

Activities	Rec Hrs	Voice %	Dt (sec)	Dc	Dd	Fo	Po	dB SPL	PS	Alpha ratio	dB 1-3 kHz	LTAS slope	Jitter %	Shim %	HNR
Non-Sing															
Day 1	14.57	10.41	5460.75	805.08	4339.88	151.87	142.76	77.92	29.26	-25.58	-58.89	-0.0058	3.76	13.52	10.11
Day 2	12.87	8.95	4146.18	647.36	3108.16	161.90	149.32	75.76	28.84	-23.66	-58.02	-0.0053	4.22	15.14	9.17
Day 3	12.53	10.86	4901.10	709.48	4045.85	152.66	136.86	78.89	27.85	-24.77	-57.89	-0.0058	4.12	15.88	8.34
MEAN	13.32	10.15	4836.01	720.64	3831.30	155.13	142.47	77.63	28.67	-24.74	-58.30	-0.0057	4.02	14.78	9.25
MEAN per hour			363.00	54.09	287.59										
TOTALS	39.97		14508.03	2161.92	11493.89										
Solo Singing															
Day1	0.60	44.70	965.58	202.47	987.76	209.32	210.07	79.65	46.82	-25.50	-57.45	-0.0060	2.12	9.48	16.56
Day2	2.17	34.17	2665.44	506.20	2571.30	186.51	193.40	79.29	39.98	-26.44	-57.83	-0.0067	2.66	10.92	14.21
Day3	1.40	19.91	1003.53	206.15	1171.68	203.14	207.65	82.88	34.90	-25.63	-56.46	-0.0065	2.90	10.21	13.39
MEAN	1.39	33.28	1544.85	304.94	1576.91	194.81	200.01	80.14	40.34	-26.07	-57.46	-0.0065	2.60 %	10.47 %	14.53
MEAN per hour			1112.29	219.56	1135.38										
TOTALS	4.17		4634.55	914.83	4730.74										
Choral Singing															
Day1	No choral singing due to opera rehearsal														
Day2															
Day3															
MEAN															
MEAN per hour															
TOTALS															

Note: "Activities" data do not include vocal dose information from the vocal tasks that were completed each day, while the "Full Days" data do include these data, so the "Activities" dose totals will not equal the "Full Days" totals when added together.

Participant 16: Baritone – Age 20

Full Days	Rec Hrs	Voice %	Dt (sec)	Dc	Dd	Fo	Po	dB SPL	PS	Alpha ratio	dB 1-3 kHz	LTAS slope	Jitter %	Shim %	HNR
Day 1	14.85	8.42	4503.33	731.34	4806.69	164.28	160.49	82.79	29.76	-22.93	-55.67	-0.0062	3.85	12.91	11.35
Day 2	14.25	9.77	5013.69	795.96	5113.99	160.63	156.89	82.13	30.76	-23.24	-56.07	-0.0059	3.85	13.43	10.73
Day 3	15.40	10.11	5606.64	922.76	5967.23	164.03	165.12	82.74	32.13	-24.44	-58.94	-0.0055	3.35	12.16	12.38
MEAN	14.83	9.50	5041.22	816.69	5295.97	162.98	161.04	82.55	30.98	-23.60	-57.03	-0.0058	3.66	12.80	11.53
MEAN per hr			339.86	55.06	357.03										
TOTALS	44.50		15123.66	2450.06	15887.91										

Activities	Rec Hrs	Voice %	Dt (sec)	Dc	Dd	Fo	Po	dB SPL	PS	Alpha ratio	dB 1-3 kHz	LTAS slope	Jitter %	Shim %	HNR
Non-Sing															
Day 1	13.12	6.38	3011.85	446.55	2491.25	153.34	142.80	79.23	25.73	-22.17	-55.62	-0.0059	4.56	15.17	9.17
Day 2	12.00	6.98	3017.19	419.71	2371.66	144.25	133.72	78.76	26.73	-22.90	-56.92	-0.0056	4.48	15.36	8.90
Day 3	13.58	6.80	3326.40	483.86	2784.90	147.64	143.27	79.49	27.33	-23.68	-58.92	-0.0054	4.07	14.20	10.10
MEAN	12.90	6.73	3118.48	450.04	2549.27	148.41	140.05	79.17	26.61	-22.94	-57.20	-0.0056	4.37	14.89	9.41
MEAN per hour			241.74	34.89	197.62										
TOTALS	38.70		9355.44	1350.12	7647.80										
Solo Singing															
Day1	1.62	21.52	1252.71	247.94	2057.84	194.99	200.55	91.01	39.38	-23.84	-54.42	-0.0068	2.52	8.65	14.71
Day2	2.13	23.28	1787.88	344.61	2533.52	191.14	194.23	87.77	36.31	-23.33	-53.91	-0.0063	2.94	10.67	13.12
Day3	1.72	34.23	2115.72	415.14	3030.33	192.98	199.11	88.02	39.25	-25.46	-58.65	-0.0058	2.27	8.90	15.77
MEAN	1.82	27.35	1718.77	335.90	2540.57	192.82	197.78	88.66	38.25	-24.32	-55.96	-0.0062	2.57	9.46	14.59
MEAN per hour			943.23	184.33	1394.21										
TOTALS	5.47		5156.31	1007.69	7621.70										
Choral Singing															
Day1	No choral singing due to opera rehearsal														
Day2															
Day3															
MEAN															
MEAN per hour															
TOTALS															

Note: “Activities” data do not include vocal dose information from the vocal tasks that were completed each day, while the “Full Days” data do include these data, so the “Activities” dose totals will not equal the “Full Days” totals when added together.

Participant 18: Soprano – Age 21

Full Days	Rec Hrs	Voice %	Dt (sec)	Dc	Dd	Fo	Po	dB SPL	PS	Alpha ratio	dB 1-3 kHz	LTAS slope	Jitter %	Shim %	HNR
Day 1	13.38	11.52	5551.83	1928.11	4818.36	337.29	364.24	75.71	22.62	-21.33	-56.31	-0.0040	4.42	18.01	7.73
Day 2	11.98	12.20	5265.00	1938.13	5019.61	359.86	380.47	77.07	25.59	-21.51	-55.32	-0.0044	3.78	15.83	10.04
Day 3	17.28	4.26	2649.15	835.71	2542.44	331.55	299.26	78.54	31.25	-20.17	-53.91	-0.0042	3.19	14.32	11.21
MEAN	14.22	10.04	4488.66	1567.32	4126.80	344.58	354.86	76.91	25.84	-21.12	-55.35	-0.0042	3.88	16.29	9.46
MEAN per hr			315.73	110.25	290.28										
TOTALS	42.65		13465.98	4701.96	12380.41										

Activities	Rec Hrs	Voice %	Dt (sec)	Dc	Dd	Fo	Po	dB SPL	PS	Alpha ratio	dB 1-3 kHz	LTAS slope	Jitter %	Shim %	HNR
Non-Sing															
Day 1	11.08	6.78	2704.14	775.04	2253.91	292.13	276.85	76.39	19.74	-21.09	-56.29	-0.0040	5.05	19.08	6.10
Day 2	10.28	7.02	2597.25	906.42	2315.45	358.68	333.46	75.96	24.94	-18.97	-54.10	-0.0037	4.08	16.45	8.52
Day 3	17.20	4.06	2513.22	792.74	2443.39	332.53	298.41	78.87	31.08	-20.13	-53.88	-0.0042	3.28	14.42	11.11
MEAN	12.86	5.98	2604.87	824.73	2337.58	326.43	302.71	77.04	24.66	-20.09	-54.87	-0.0039	4.23	16.89	8.31
MEAN per hour			202.63	64.15	181.83										
TOTALS	38.57		7814.61	2474.20	7012.75										
Solo Singing															
Day1	0.45	36.24	587.04	293.96	542.84	493.36	510.60	74.08	34.17	-20.12	-52.92	-0.0044	3.08	11.45	14.55
Day2	0.77	51.97	1434.30	631.34	1560.19	428.79	452.38	78.91	33.58	-24.52	-56.62	-0.0054	2.23	10.78	16.16
Day3															
MEAN	0.61	47.40	1010.67	462.65	1051.52	448.88	467.91	77.51	33.76	-23.15	-55.47	-0.0050	2.49	10.98	15.56
MEAN per hour			1661.38	760.53	1728.52										
TOTALS	1.22		2021.34	925.31	2103.03										
Choral Singing															
Day1	1.75	34.46	2170.83	833.55	1955.54	357.87	429.47	75.40	22.84	-21.88	-57.13	-0.0039	4.07	18.66	7.70
Day2	0.83	39.01	1170.33	382.32	1086.07	299.73	381.39	77.18	18.65	-23.65	-56.38	-0.0049	4.74	19.75	6.94
Day3															
MEAN	1.29	36.05	1670.58	607.93	1520.81	336.79	413.70	76.02	21.32	-22.52	-56.86	-0.0043	4.31	19.05	7.42
MEAN per hour			1293.35	470.66	1177.40										
TOTALS	2.58		3341.16	1215.86	3041.61										

Note: “Activities” data do not include vocal dose information from the vocal tasks that were completed each day, while the “Full Days” data do include these data, so the “Activities” dose totals will not equal the “Full Days” totals when added together.

Participant 19: Tenor – Age 23

Full Days	Rec Hrs	Voice %	Dt (sec)	Dc	Dd	Fo	Po	dB SPL	PS	Alpha ratio	dB 1-3 kHz	LTAS slope	Jitter %	Shim %	HNR
Day 1	15.32	18.02	9934.68	2231.68	12592.54	223.17	226.14	83.77	45.94	-24.11	-59.73	-0.0062	2.43	8.71	16.37
Day 2	14.47	23.13	12047.31	2601.85	14304.97	211.19	220.84	82.64	42.67	-23.69	-58.01	-0.0057	2.19	8.52	16.63
Day 3	17.13	8.99	5547.30	1071.01	6286.31	194.10	192.01	82.61	42.51	-24.15	-59.94	-0.0057	2.70	10.55	14.12
MEAN	15.64	18.44	9176.43	1968.18	11061.27	212.08	216.94	83.04	43.82	-23.93	-59.02	-0.0059	2.38	9.00	16.03
MEAN per hr			586.77	125.85	707.29										
TOTALS	46.92		27529.29	5904.55	33183.82										

Activities	Rec Hrs	Voice %	Dt (sec)	Dc	Dd	Fo	Po	dB SPL	PS	Alpha ratio	dB 1-3 kHz	LTAS slope	Jitter %	Shim %	HNR
Non-Sing															
Day 1	12.03	10.81	4684.56	932.25	5135.60	199.56	198.42	81.63	38.85	-24.10	-60.48	-0.0054	2.99	10.70	13.49
Day 2	11.42	14.86	6107.94	1182.41	6144.07	190.69	196.62	80.09	39.09	-24.28	-59.53	-0.0052	2.83	10.00	14.12
Day 3	16.12	6.91	4011.00	728.46	4195.65	183.61	179.56	81.53	38.85	-24.03	-59.95	-0.0052	3.13	12.13	12.17
MEAN	13.19	11.43	4934.50	947.71	5158.44	191.60	192.54	80.97	38.95	-24.16	-59.94	-0.0053	2.96	10.80	13.40
MEAN per hour			374.14	71.86	391.12										
TOTALS	39.57		14803.50	2843.12	15475.32										
Solo Singing															
Day1	1.50	45.00	2429.76	586.68	3537.21	240.13	242.78	86.39	56.67	-23.36	-58.91	-0.0071	1.78	5.78	20.91
Day2	0.38	71.59	987.90	241.53	1561.52	244.40	244.58	88.35	57.50	-23.68	-55.98	-0.0077	1.15	4.47	23.08
Day3	0.92	41.15	1358.07	309.02	1891.53	226.31	228.78	85.81	52.22	-24.58	-60.16	-0.0069	1.64	6.92	18.45
MEAN	0.93	49.40	1591.91	379.08	2330.09	237.05	239.19	86.63	55.57	-23.78	-58.66	-0.0072	1.61	5.84	20.65
MEAN per hour			1705.62	406.16	2496.52										
TOTALS	2.80		4775.73	1137.24	6990.26										
Choral Singing															
Day1	1.70	43.84	2682.90	685.56	3757.83	251.22	259.91	85.14	49.34	-24.80	-59.13	-0.0067	2.08	8.04	17.05
Day2	2.58	51.50	4789.17	1147.31	6412.97	231.99	247.09	84.68	43.93	-22.86	-56.35	-0.0059	1.63	7.58	18.27
Day3															
MEAN	2.14	48.75	3736.04	916.44	5085.40	238.95	251.66	84.84	45.89	-23.56	-57.36	-0.0062	1.79	7.75	17.83
MEAN per hour			1744.45	427.91	2374.51										
TOTALS	4.28		7472.07	1832.87	10170.81										

Note: “Activities” data do not include vocal dose information from the vocal tasks that were completed each day, while the “Full Days” data do include these data, so the “Activities” dose totals will not equal the “Full Days” totals when added together.

Participant 20: Soprano – Age 19

Full Days	Rec Hrs	Voice %	Dt (sec)	Dc	Dd	Fo	Po	dB SPL	PS	Alpha ratio	dB 1-3 kHz	LTAS slope	Jitter %	Shim %	HNR
Day 1	16.07	11.35	6562.41	2060.73	4534.07	312.25	316.16	70.94	28.88	-20.94	-52.34	-0.0058	3.23	14.18	11.73
Day 2	17.45	11.34	7123.98	2259.36	5052.53	312.33	322.45	71.64	28.03	-21.67	-52.25	-0.0063	3.19	14.00	11.65
Day 3	11.62	14.44	6039.69	1854.11	4442.39	311.05	302.61	72.72	28.24	-21.29	-52.19	-0.0062	3.34	14.29	11.52
MEAN	15.04	12.31	6575.36	2058.07	4676.33	311.90	314.21	71.75	28.37	-21.32	-52.26	-0.0061	3.25	14.15	11.64
MEAN per hr			437.06	136.80	310.83										
TOTALS	45.13		19726.08	6174.21	14028.99										

Activities	Rec Hrs	Voice %	Dt (sec)	Dc	Dd	Fo	Po	dB SPL	PS	Alpha ratio	dB 1-3 kHz	LTAS slope	Jitter %	Shim %	HNR
Non-Sing															
Day 1	15.15	10.02	5464.47	1572.75	3465.26	287.97	287.61	69.96	26.53	-20.52	-51.55	-0.0057	3.55	15.54	9.76
Day 2	16.02	8.88	5122.05	1482.52	3395.45	296.11	282.23	71.03	27.86	-21.35	-52.15	-0.0060	3.32	13.83	11.39
Day 3	10.43	11.88	4461.27	1242.49	2958.24	289.20	266.75	71.42	25.80	-20.48	-50.99	-0.0059	3.73	15.46	9.73
MEAN	13.87	10.18	5015.93	1432.59	3272.98	291.03	279.41	70.76	26.76	-20.78	-51.58	-0.0059	3.53	14.95	10.29
MEAN per hour			361.73	103.31	236.03										
TOTALS	41.60		15047.79	4297.76	9818.94										
Solo Singing															
Day1	0.55	33.98	672.78	329.70	746.01	491.02	489.10	78.57	47.20	-24.28	-57.19	-0.0066	1.03	4.36	26.31
Day2	0.57	40.52	826.56	332.49	690.18	381.33	424.44	73.18	32.93	-22.09	-52.16	-0.0074	2.49	12.82	13.92
Day3	0.40	43.64	628.35	232.68	593.41	367.36	373.14	77.14	42.02	-24.18	-55.70	-0.0074	1.26	6.84	21.24
MEAN	0.51	39.37	709.23	298.29	676.53	411.62	429.63	76.05	40.02	-23.38	-54.76	-0.0072	1.68	8.44	19.91
MEAN per hour			1402.87	590.02	1338.20										
TOTALS	1.52		2127.69	894.87	2029.60										
Choral Singing															
Day1															
Day2	0.78	35.77	1008.66	393.28	856.98	337.59	455.51	73.68	23.20	-22.72	-52.39	-0.0069	3.35	16.85	10.07
Day3	0.73	33.38	881.16	356.01	818.82	383.41	425.88	75.58	29.82	-23.16	-55.42	-0.0066	2.85	13.90	13.55
MEAN	0.76	34.65	944.91	374.64	837.90	358.07	441.03	74.56	26.16	-22.92	-53.74	-0.0068	3.13	15.53	11.62
MEAN per hour			1246.04	494.04	1104.93										
TOTALS	1.52		1889.82	749.29	1675.81										

Note: "Activities" data do not include vocal dose information from the vocal tasks that were completed each day, while the "Full Days" data do include these data, so the "Activities" dose totals will not equal the "Full Days" totals when added together.

Participant 21: Baritone – Age 19

Full Days	Rec Hrs	Voice %	Dt (sec)	Dc	Dd	Fo	Po	dB SPL	PS	Alpha ratio	dB 1-3 kHz	LTAS slope	Jitter %	Shim %	HNR
Day 1	13.68	6.91	3405.24	598.33	2911.61	172.37	179.29	77.75	36.07	-27.06	-60.80	-0.0061	3.21	10.74	14.24
Day 2	12.90	17.13	7955.28	1610.66	7538.81	198.22	207.11	78.37	42.41	-28.90	-64.47	-0.0065	2.39	8.70	17.35
Day 3	14.88	11.03	5907.69	1183.78	4515.15	200.22	200.58	73.75	37.13	-25.94	-61.64	-0.0054	2.97	11.48	13.84
MEAN	13.82	13.01	5756.07	1130.92	4988.52	194.02	199.49	76.61	39.32	-27.49	-62.76	-0.0060	2.75	10.08	15.51
MEAN per hr			416.44	81.82	360.91										
TOTALS	41.47		17268.21	3392.77	14965.57										

Activities	Rec Hrs	Voice %	Dt (sec)	Dc	Dd	Fo	Po	dB SPL	PS	Alpha ratio	dB 1-3 kHz	LTAS slope	Jitter %	Shim %	HNR
Non-Sing															
Day 1	12.93	5.47	2545.62	387.38	1984.74	149.97	154.57	77.14	33.41	-26.35	-60.09	-0.0060	3.67	11.87	12.68
Day 2	8.62	8.25	2559.57	397.87	1909.91	151.37	160.54	75.75	34.89	-27.54	-62.14	-0.0061	3.52	11.79	12.64
Day 3	12.98	7.38	3449.85	676.22	2463.34	199.19	191.70	72.78	33.87	-25.35	-61.04	-0.0050	3.58	13.01	11.52
MEAN	11.51	7.07	2851.68	487.16	2119.33	171.15	170.47	74.96	34.05	-26.29	-61.11	-0.0056	3.59	12.33	12.18
MEAN per hour			247.73	42.32	184.11										
TOTALS	34.53		8555.04	1461.47	6357.99										
Solo Singing															
Day1															
Day2	0.32	12.06	137.52	23.16	120.44	169.41	167.33	78.45	36.91	-27.31	-59.54	-0.0064	4.94	14.43	7.74
Day3	1.05	37.87	1431.39	286.76	1173.20	197.47	203.49	75.03	42.14	-26.88	-62.20	-0.0059	1.87	8.51	17.84
MEAN	0.68	35.61	784.46	154.96	646.82	195.04	200.28	75.33	41.69	-26.92	-61.97	-0.0060	2.13	9.03	16.97
MEAN per hour			1147.98	226.77	946.57										
TOTALS	1.37		1568.91	309.92	1293.64										
Choral Singing															
Day1	0.65	28.66	670.59	180.44	767.20	259.01	279.98	80.00	42.06	-29.19	-62.68	-0.0060	2.09	8.76	16.91
Day2	3.87	36.40	5066.34	1158.20	5338.84	226.23	231.05	79.67	46.65	-29.69	-65.97	-0.0066	1.77	7.06	19.95
Day3	0.75	31.62	853.86	191.66	752.62	215.92	233.95	75.51	40.82	-26.84	-63.43	-0.0059	2.39	10.67	16.25
MEAN	1.76	34.99	2196.93	510.10	2286.22	228.25	236.30	79.16	45.40	-29.26	-65.29	-0.0065	1.88	7.72	19.14
MEAN per hour			1251.42	290.56	1302.28										
TOTALS	5.27		6590.79	1530.29	6858.67										

Note: “Activities” data do not include vocal dose information from the vocal tasks that were completed each day, while the “Full Days” data do include these data, so the “Activities” dose totals will not equal the “Full Days” totals when added together.

Participant 22: Soprano – Age 24

Full Days	Rec Hrs	Voice %	Dt (sec)	Dc	Dd	Fo	Po	dB SPL	PS	Alpha ratio	dB 1-3 kHz	LTAS slope	Jitter %	Shim %	HNR
Day 1	13.78	8.38	4160.40	1272.22	2267.66	312.51	299.05	65.43	28.54	-24.35	-58.33	-0.0049	3.66	14.51	9.79
Day 2	13.13	8.18	3868.56	1242.68	2212.66	327.81	314.60	66.06	29.76	-24.75	-56.79	-0.0055	3.11	12.19	12.13
Day 3	15.15	11.54	6292.56	1959.36	3514.07	319.78	302.14	65.76	28.69	-24.18	-57.63	-0.0049	3.47	13.98	10.59
MEAN	14.02	9.70	4773.84	1491.42	2664.80	319.95	304.74	65.75	28.95	-24.39	-57.59	-0.0051	3.42	13.63	10.79
MEAN per hr			340.45	106.36	190.04										
TOTALS	42.07		14321.52	4474.27	7994.39										

Activities	Rec Hrs	Voice %	Dt (sec)	Dc	Dd	Fo	Po	dB SPL	PS	Alpha ratio	dB 1-3 kHz	LTAS slope	Jitter %	Shim %	HNR
Non-Sing															
Day 1	12.00	6.68	2884.53	812.14	1444.56	288.57	274.31	64.49	28.45	-23.88	-57.51	-0.0047	3.65	15.10	9.23
Day 2	11.22	6.78	2739.06	822.19	1520.41	309.48	290.74	66.05	29.52	-24.97	-57.55	-0.0053	3.28	12.29	11.71
Day 3	11.95	9.69	4167.99	1200.46	2252.48	302.98	271.30	65.65	28.20	-24.08	-58.34	-0.0048	3.82	14.44	9.72
MEAN	11.72	7.99	3263.86	944.93	1739.15	300.36	277.84	65.42	28.63	-24.26	-57.88	-0.0049	3.62	14.06	10.11
MEAN per hour			278.43	80.61	148.36										
TOTALS	35.17		9791.58	2834.80	5217.45										
Solo Singing															
Day1	1.68	18.46	1118.91	413.17	746.47	381.53	357.23	68.20	27.26	-25.47	-60.32	-0.0052	4.11	14.15	9.71
Day2	1.83	15.39	1015.56	388.00	646.97	382.58	381.72	66.85	29.30	-24.31	-54.56	-0.0059	2.93	12.87	12.10
Day3	3.08	17.82	1942.44	701.33	1181.57	358.08	364.20	66.52	29.41	-24.48	-56.06	-0.0053	2.85	13.42	11.96
MEAN	2.20	17.39	1358.97	500.83	858.34	370.40	366.68	67.06	28.81	-24.70	-56.84	-0.0054	3.21	13.48	11.39
MEAN per hour			617.71	227.65	390.15										
TOTALS	6.60		4076.91	1502.49	2575.01										
Choral Singing															
Day1	No choral rehearsal – Break after a major weekend performance														
Day2															
Day3															
MEAN															
MEAN per hour															
TOTALS															

Note: “Activities” data do not include vocal dose information from the vocal tasks that were completed each day, while the “Full Days” data do include these data, so the “Activities” dose totals will not equal the “Full Days” totals when added together.

Participant 24: Baritone – Age 23

Full Days	Rec Hrs	Voice %	Dt (sec)	Dc	Dd	Fo	Po	dB SPL	PS	Alpha ratio	dB 1-3 kHz	LTAS slope	Jitter %	Shim %	HNR
Day 1	12.28	21.08	9322.38	1554.75	8709.16	165.89	167.66	80.19	33.77	-23.54	-59.03	-0.0043	2.67	12.01	12.21
Day 2	11.72	18.84	7947.18	1265.80	7683.42	156.30	162.08	81.63	33.14	-25.30	-59.76	-0.0052	2.79	11.52	12.19
Day 3	13.30	20.68	9903.90	1707.17	9179.72	167.17	177.70	79.43	32.47	-22.40	-57.60	-0.0040	2.75	12.23	11.24
MEAN	12.43	20.28	9057.82	1509.24	8524.10	163.63	169.59	80.33	33.11	-23.62	-58.71	-0.0045	2.73	11.95	11.84
MEAN per hr			728.51	121.39	685.58										
TOTALS	37.30		27173.46	4527.72	25572.29										

Activities	Rec Hrs	Voice %	Dt (sec)	Dc	Dd	Fo	Po	dB SPL	PS	Alpha ratio	dB 1-3 kHz	LTAS slope	Jitter %	Shim %	HNR
Non-Sing															
Day 1	8.20	14.17	4183.35	678.27	3811.16	160.61	163.57	80.09	31.49	-24.29	-59.18	-0.0045	3.24	13.05	10.60
Day 2	9.42	13.95	4727.91	699.14	4230.72	148.26	147.50	80.92	31.49	-25.38	-60.07	-0.0049	3.10	11.99	11.39
Day 3	10.90	15.16	5942.91	967.30	4961.15	157.75	167.74	78.05	29.87	-23.21	-57.98	-0.0042	3.09	12.77	10.73
MEAN	9.51	14.50	4951.39	781.57	4334.34	155.53	160.11	79.54	30.84	-24.20	-58.98	-0.0045	3.13	12.60	10.90
MEAN per hour			520.89	82.22	455.98										
TOTALS	28.52		14854.17	2344.71	13003.03										
Solo Singing															
Day1	0.88	36.12	1148.73	217.06	1229.57	189.23	188.70	81.77	47.05	-23.74	-58.43	-0.0044	1.86	7.36	17.11
Day2	1.33	38.09	1828.26	344.65	2109.14	178.45	197.04	83.74	36.37	-26.40	-59.36	-0.0060	2.77	11.52	12.22
Day3	0.47	49.32	828.54	172.03	1144.13	207.42	207.83	86.62	48.93	-20.80	-56.21	-0.0038	1.46	6.14	15.37
MEAN	0.89	39.94	1268.51	244.58	1494.28	188.34	196.87	83.77	42.53	-24.31	-58.36	-0.0050	2.19	9.01	14.45
MEAN per hour			1418.21	273.44	1670.62										
TOTALS	2.68		3805.53	733.74	4482.84										
Choral Singing															
Day1	3.12	34.46	3866.13	638.38	3530.78	164.20	166.10	79.72	31.95	-22.82	-59.07	-0.0041	2.33	12.30	12.36
Day2	0.83	39.75	1192.53	196.42	1178.59	161.00	168.34	81.36	35.96	-23.71	-59.34	-0.0048	1.96	10.69	14.16
Day3	1.87	44.25	2973.93	546.49	2949.37	176.08	192.29	80.13	33.10	-21.19	-57.13	-0.0038	2.54	13.17	10.76
MEAN	1.94	38.87	2677.53	460.43	2552.91	168.22	175.96	80.12	32.95	-22.33	-58.38	-0.0041	2.36	12.40	12.01
MEAN per hour			1380.96	237.47	1316.69										
TOTALS	5.82		8032.59	1381.29	7658.74										

Note: "Activities" data do not include vocal dose information from the vocal tasks that were completed each day, while the "Full Days" data do include these data, so the "Activities" dose totals will not equal the "Full Days" totals when added together.

Participant 25: Soprano – Age 20

Full Days	Rec Hrs	Voice %	Dt (sec)	Dc	Dd	Fo	Po	dB SPL	PS	Alpha ratio	dB 1-3 kHz	LTAS slope	Jitter %	Shim %	HNR
Day 1	15.00	12.26	6618.93	2458.59	4478.82	361.00	382.37	68.89	31.05	-23.29	-57.53	-0.0048	2.63	11.34	15.00
Day 2	14.83	11.97	6390.66	2259.45	4676.72	352.00	355.21	71.02	31.96	-23.39	-56.33	-0.0050	2.94	12.57	12.97
Day 3	17.73	10.88	6948.72	2346.89	4951.35	344.11	331.12	70.89	32.52	-23.74	-57.00	-0.0049	3.07	12.34	12.92
MEAN	15.86	11.68	6652.77	2354.98	4702.30	326.10	355.81	70.27	31.85	-23.48	-56.96	-0.0049	2.88	12.08	13.63
MEAN per hr			419.59	148.53	296.57										
TOTALS	47.57		19958.31	7064.93	14106.89										

Activities	Rec Hrs	Voice %	Dt (sec)	Dc	Dd	Fo	Po	dB SPL	PS	Alpha ratio	dB 1-3 kHz	LTAS slope	Jitter %	Shim %	HNR
Non-Sing															
Day 1	13.05	9.93	4662.57	1702.58	3025.51	356.28	374.52	68.19	29.44	-23.02	-57.86	-0.0046	2.77	12.13	13.95
Day 2	12.83	7.34	3391.38	1077.32	2276.92	326.70	307.79	70.02	28.89	-23.44	-56.83	-0.0047	3.36	13.42	10.95
Day 3	16.58	8.72	5205.51	1655.11	3564.76	328.48	306.94	70.55	30.42	-24.36	-57.81	-0.0049	3.43	13.33	11.58
MEAN	14.16	8.79	4419.82	1478.34	2955.73	337.77	330.99	69.58	29.68	-23.65	-57.57	-0.0047	3.18	12.93	12.25
MEAN per hour			312.23	104.44	208.80										
TOTALS	42.47		13259.46	4435.01	8867.19										
Solo Singing															
Day1	1.90	27.02	1855.86	721.36	1391.06	373.90	403.91	70.74	34.62	-23.91	-56.76	-0.0051	2.35	9.61	17.39
Day2	1.90	41.63	2847.66	1131.10	2310.66	383.78	411.13	72.45	35.30	-23.30	-55.71	-0.0053	2.52	11.70	15.18
Day3	1.05	42.27	1597.86	644.56	1300.26	397.45	409.43	72.33	38.85	-21.55	-54.31	-0.0046	1.98	9.70	16.85
MEAN	1.62	37.49	2100.46	832.34	1667.33	384.32	408.57	71.91	35.99	-23.04	-55.66	-0.0051	2.33	10.58	16.25
MEAN per hour			1299.25	514.85	1031.34										
TOTALS	4.85		6301.38	2497.03	5001.98										
Choral Singing															
Day1	No choral rehearsal – Final week of the semester & rehearsals completed														
Day2															
Day3															
MEAN															
MEAN per hour															
TOTALS															

Note: "Activities" data do not include vocal dose information from the vocal tasks that were completed each day, while the "Full Days" data do include these data, so the "Activities" dose totals will not equal the "Full Days" totals when added together.